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FINAL PROJECT REPORT

COMMERCE ENERGY BIOGAS/PV MINIGRID RENEWABLE RESOURCES PROGRAM

Making Renewables Part of an Affordable and Diverse Electric System in California

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PREFACE

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ABSTRACT

The purpose of this project was to increase biogas power generation at wastewater treatment plants. The project had two elements: ultrasound and gas cleaning. Under the first element, two ultrasound technologies were tested to determine their effectiveness in increasing solids destruction and biogas production. Under the second element, various biogas cleaning systems were tested to determine their cost-effectiveness in making renewable energy more affordable.

- Two ultrasound systems were installed at the City of Riverside Wastewater Treatment Plant. Results obtained from pilot testing and installation and operation costs were described in previous reports. This report summarizes the technical, environmental, and economic performance of the ultrasound units.
- Three gas cleaning systems were designed, installed, and testedat the Inland Empire Utilities Agency Regional Plant 1 facility. The first system included a chiller to remove moisture and siloxane. The second system was a biological scrubber installed to remove hydrogen sulfide from the gas stream. The scrubber was compared to the current iron sponge method used at the facility. The third system involved using different absorption media (a graphite-based media and a polymer-based media) for siloxane removal.
- The authors concluded that ultrasound technology could have beneficial effects on systems where there was not adequate time for digestion. Newer sonic horns larger than six kilowatts were not recommended for installations where holding times were not limited. Improved gas cleaning technologies were very important to the economics of biogas projects. The biological scrubber was the most cost-effective, reliable, and low-labor unit. Biological scrubbers reduced the life cycle cost of hydrogen sulfide removal systems and allowed reliable hydrogen sulfide removal from the digester gas without the daily use of chemicals.

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Introduction

The Chino Basin in California is rich in photovoltaic (PV) and biogas resources and is a rapidly growing area with substantial and increasing electrical loads. The underlying goal of the PIER Renewable Program is to identify potential Building Integrated PV (BIPV) and biogas energy projects, bring innovative technologies and business practices to these projects, assess the benefit to the local electricity distribution system (the "mini-grid"), and then use the findings to develop a business model for siting cost-effective, renewable energy projects.

This report summarizes the work conducted and the results of the data collection and analysis performed for the "Enhanced Energy Recovery through Optimization of Anaerobic Digestion and Microturbines" Project. Under this project, two different types of technologies were evaluated: (1) systems for optimizing anaerobic digestion gas production (for example, ultrasound), and (2) gas cleaning systems for microturbines. Anaerobic digestion refers to a process that does not require oxygen. Economics for each technology, including installation and maintenance costs and the value of the environmental benefits achieved were discussed in this report.

Project Purpose

The overall goal of this project was to increase biogas power generation at wastewater treatment plants. The project focused on two elements: ultrasound and gas cleaning. The ultrasound element grew out of tasks that examined ultrasound, thermal hydrolysis, and other technologies that enhanced the anaerobic digestion process leading to higher levels of biogas production. Hydrolysis refers to the breakdown of cellular material and thermal hydrolysis uses high temperature and pressure to accomplish this process. The intent of using ultrasound was to increase solids destruction and biogas production, thus increasing the amount of biogas available for power generation and reducing the amount of residual material requiring offsite disposal. Two ultrasound technologies were tested to determine their effectiveness in breaking down cell walls in sewage sludge before entering an anaerobic digester.

The second element involved the installation and testing of biogas cleaning systems to determine their cost-effectiveness in making renewable energy more affordable. Gas cleaning systems are increasingly being used in biogas power generation systems. The gas cleaning systems facilitate the improved performance of microturbines, engine-generators, and other systems, allowing them to operate for longer periods of time between maintenance activities and lowering emissions.

The specific objectives of the project were:

- Increasing and optimizing digester gas production through thermal hydrolysis and ultrasound processes.
- Developing and optimizing cost-effective gas cleanup systems.
- Evaluating and quantifying environmental benefits that result from using microturbines at sewage treatment plants.

- Evaluating performance and cost during operation so sewage treatment plants have greater certainty about the cost and reliability of using microturbines.

Project Results

The projected and actual outcomes for each objective are summarized in Table ES-1. The outcomes are discussed further in sections 3 and 4 of this report.

Table ES-1: Project 2.2 Objectives, Projected Outcomes, and Actual Outcomes

Objective	Projected Outcome	Actual Outcome
Increase and optimize digester gas production through thermal hydrolysis and ultrasound processes.	The focus for the digester gas production improvement processes (thermal hydrolysis and ultrasound) will be on evaluating the systems, their impact on gas production, and their cost-effectiveness. An evaluation of the digester gas production and quality as well as biosolids reduction rate and dewatering characteristics will be presented. The installation and operating costs for the systems will be established for full-scale facilities. The cost-effectiveness evaluation will include the overall installation and operating cost compared to the benefits of improved gas production and reduced biosolids mass for disposal/reuse. A detailed evaluation and quantification of environmental benefits for each of the systems will also be developed.	The *Task 2.2.1 Process Selection Report for Wastewater Treatment Plants* (Process Selection Report) (CH2M HILL, 2003) concluded that ultrasound had a greater potential for application in Southern California than thermal hydrolysis. As a result, ultrasound was the focus of this evaluation. IWE.tec and Sonico ultrasound systems were chosen for evaluation. IWE.tec and Sonico systems were designed and installed at the City of Riverside Wastewater Treatment Plant. Testing of the systems was conducted in accordance with the Test Plan documented in the Task *2.2.2 Site Selection and Test Plan Report* (CH2M HILL, 2004). Findings were reported in the six quarterly reports, which included summaries of the digester gas production and biosolids reduction and dewatering processes. Installation and operating costs were also summarized in the quarterly reports. Technical, environmental, and economic performance of the ultrasound units were summarized in this report.
Develop and optimize cost-effective gas cleanup	At least three gas cleaning systems will be defined and optimized. It is anticipated that one of these systems	Three gas cleaning systems were designed, installed, and tested at the Inland Empire Utilities Agency

Table ES-1: Project 2.2 Objectives, Projected Outcomes, and Actual Outcomes

Objective	Projected Outcome	Actual Outcome
systems.	will involve hydrogen sulfide (H_2S) removal, gas drying, and siloxane removal. A second system will likely involve gas drying and siloxane removal. A third system will also be formulated, although the parameters have not been defined,. The installation and operating costs for each system will be determined for the full project life cycle.	Regional Plant 1 (IEUA RP-1) facility in accordance with the Test Plan. The first system included a chiller that removed moisture and siloxane. The second system was a biological scrubber that was installed to remove H_2S from the gas stream. The scrubber was compared to the current iron sponge technology used at the facility. The third system involved using different absorption media (graphite- and polymer-based) for siloxane removal. The installation and operating costs for each system were reported in the quarterly reports.
Evaluate and quantify the environmental benefits that result from using microturbines at sewage treatment plants.	A detailed evaluation and quantification of environmental benefits for each of the systems described above (the gas cleanup systems) will be developed. These will be presented in the context of the Capstone microturbine. A comparison to the existing conditions will be included in this assessment. The expected outcome will be to increase gas production by 10 to 20 percent at an existing wastewater treatment plant, which ranges in size from one to 50 million gallons per day (MGD). The contractor will seek to improve the efficiency and cost-effectiveness of gas cleaning systems used on microturbines, but in this part of the project it may make more sense to test the work at an existing facility rather than install new generation.	Technical, environmental, and economic performance of the gas cleaning units were summarized in Section 4 of this final report. Each of the systems evaluated was compared to the existing gas treatment method (iron sponge).

Table ES-1: Project 2.2 Objectives, Projected Outcomes, and Actual Outcomes

Objective	Projected Outcome	Actual Outcome
	The expected cumulative generating capacities resulting from this project are expected to range from 60 kilowatts (kW) to 1 megawatt (MW).	
Evaluate performance and cost during operation so sewage treatment plants have greater certainty about the cost and reliability of using microturbines.	The results of this evaluation will be documented in a report that evaluates the cost and effectiveness of the various gas cleanup systems for each of the microturbines considered. The economics of the systems will be evaluated based on the value of electricity produced and waste heat recovered and used at the sewage treatment plant. Various alternatives will be compared by examining the net present value of different systems and the rate of return based on funds utilized.	Results from pilot testing of the gas systems were summarized in the quarterly reports. The quarterly reports discussed the effectiveness and cost (installation and operation) of each of the gas systems. This report summarized the economics of each of the systems and compared the net present value of each system.

The main conclusions from this project included:

- Ultrasound technology could have beneficial effects on systems that do not have adequate time for digestion. Treatment of the sludge by either system did not significantly increase gas production or solids destruction in the City of Riverside once operational changes were made and all systems had adequate holding time.
- If ultrasound was used, sonic horns in the size range of six kW or less were more reliable than the larger-sized horns vendors have manufactured recently. Newer sonic horns larger than six kW were not recommended for installations where holding times were not limited. Ultrasound technology vendors have changed their marketing plans since the testing under this program was completed and were focusing on smaller-sized sonic horns.
- Improved gas cleaning technologies were very important to the economics of biogas projects. The gas cleaning systems tested performed well. The biological scrubber was the most cost-effective, reliable, and low labor unit, and its use eliminated the need for chemicals, thereby saving money and reducing environmental impacts. SagPak monitoring results showed siloxane removal. However, media capacity was not completely determined within the project test period, so the unit's useful life was not completely assessed. The other systems functioned well, but did not have the rate of return and were not as reliable as the biological scrubber.

- Biological scrubbers reduced the life cycle cost of H_2S removal systems as compared to iron sponges or other more standard control technologies. The biological scrubber performed well and was a cost-effective system. It had the capacity to be an easily implementable technology with robust performance controls, allowing reliable H_2S removal from digester gas without the daily use of chemicals.

The primary recommendation for future activity was to initiate a technology transfer program that disseminated information about the technical, economic, and environmental benefits of biological scrubbers so that future biogas projects can adopt this technology. In addition, it is recommended that additional work be undertaken to optimize combined chiller- and media-based gas cleaning systems to most cost-effectively remove H_2S, siloxane, and moisture from biogas. These systems would significantly improve the performance of biogas generation projects and reduce their life cycle costs.

Project Benefits

Findings from this project confirmed that ultrasound technology could improve digester performance. Ultrasound technology could be particularly cost-effective in wastewater treatment plants where the systems are stressed,. Ultrasound technology was most effective when applied in specialized rather than general applications. Payback time could be long if the conditions were not right.

The results of the gas cleaning tests showed that the biological H_2S scrubbers could be efficient, easy to operate, non-labor intensive, and cost-effective units for implementation at other facilities where H_2S removal from biogas is needed prior to cogeneration. The biological scrubber had significant economic and environmental benefits and was a good candidate to be installed at many other locations in California. The testing of the unit at IEUA RP-1 documented that it could be installed efficiently at existing facilities, meaning that it could be used in a variety of applications where H_2S removal from gas streams is needed with low operational cost.

Siloxane removal systems removed siloxane from the gas stream, although they were not as reliable as biological scrubbers. These units could be readily implemented at California facilities after further assessments of media useful life.

CHAPTER 1: Introduction

In June 2001, the Commerce Energy Team was awarded a programmatic contract under the California Energy Commission's (Energy Commission's) Public Interest Energy Research (PIER) Renewable Program to conduct research on strategies for making renewable energy more affordable in California. The team devised an approach consisted of the following steps: (1) Assess the combined potential of biogas and photovoltaic (PV) resources in a defined study area, and (2) Identify how these resources can be developed in a complementary and cost-effective manner. Research was conducted in a practical, real-world setting so that the findings could be applied elsewhere in California and thereby benefit more California ratepayers. The local area selected for renewable energy research activities is the Chino Basin, referred to in this report as the "study area."

1.1 Background and Overview

The Chino Basin is rich in PV and biogas resources. Moreover, it is a rapidly growing area with substantial and increasing electrical loads. The underlying goal of the PIER Renewable Program is to identify potential Building Integrated PV (BIPV) and biogas energy projects, bring innovative technologies and business practices to these projects, assess the benefit to the local electricity distribution system (the "mini-grid"), and then use the findings to develop a business model for siting cost-effective, renewable energy projects. A description of the PIER Renewable Program, including the results of some of the work undertaken to date, is presented on the project Web site: http://www.pierminigrid.org.

Project 2.2, Enhanced Energy Recovery Through Optimization of Anaerobic Digestion and Microturbines, is devoted to research on improving energy recovery from biogas derived from anaerobic digestion. This final report, written under Task 2.2.6, Prepare Final Report for Project 2.2, summarizes the work conducted and the results of the data and analysis work performed under tasks 2.2.1 through 2.2.5. Economics for each project, including installation and maintenance costs and value of environmental benefits achieved, are discussed.

1.1.1 Project 2.2 Background

The goal of Project 2.2 is to increase biogas power generation at wastewater treatment plants. The Project has two elements: ultrasound and gas cleaning. The ultrasound element grew out of tasks that examined ultrasound, thermal hydrolysis, and other technologies that enhanced the anaerobic digestion process leading to higher levels of biogas production. The intent of using ultrasound is to increase solids destruction and biogas production, thus increasing the amount of biogas available for power generation and reducing the amount of residual material requiring offsite disposal. Under this element, two ultrasound technologies were tested to determine their effectiveness in breaking down cell walls in sewage sludge prior to entering an anaerobic digester.

The second element involves the installation and testing of biogas cleaning systems to determine their cost-effectiveness in making renewable energy more affordable. Gas cleaning systems are increasingly more often being used in biogas power generation systems. The gas cleaning systems facilitate the improved performance of microturbines, engine-generators, and other systems, allowing them to operate for longer periods of time between maintenance activities and lowering emissions.

1.1.1.1 Relationship to Gas Cleaning in Project 3.1

Because the overall goal of Project 2.2 was to increase biogas generation at wastewater treatment plants, the anaerobic digestion optimization and treatment of biogas generated during the improved digestion operation are directly related to the biogas cleaning and co-digestion planning and test activities that were completed under Project 3.1. In general, more effective gas cleaning systems are being used more frequently in biogas power generation systems. The gas cleaning systems facilitate the improved performance of microturbines, engine-generators, and other systems, allowing them to operate for longer periods of time between maintenance activities and lowering emissions. Hence, by identifying and optimizing the most feasible gas cleaning technologies, those technologies could be used to clean the biogas generated with co-digestion implementation (Project 3.1) before the biogas is used in the cogeneration system. A comparison of the effectiveness of different gas cleaning technologies under Projects 2.2 and 3.1 will allow identification of feasible gas cleaning methods.

1.1.1.2 Relationship to Co-Digestion Work in Project 3.1

Both elements of Project 2.2—evaluation and testing of optimization of anaerobic digestion gas production and evaluation of gas cleaning technologies for microturbine operation—are directly related to the Project 3.1 activities. The intent of using ultrasound (the chosen optimization technology) was to test the potential of achieving increased solids destruction and as a result increased biogas production. This could result in increasing the amount of biogas available for power generation and reducing the amount of residual material requiring offsite disposal. The gas cleaning element of this project was intended to provide solutions and feasible technologies for the cleaning the biogas that will be generated during co-digestion under Project 3.1. The results of biogas cleaning systems testing directly relates to co-digestion in determining the cost-effectiveness of the gas cleaning technologies and the affordability of renewable energy.

1.1.2 Project 2.2 Overview

Project 2.2 consists of the following tasks:

- Task 2.2.1—Process Selection: Evaluate and select two sets of processes. The first for gas cleaning systems for microturbines and the second for optimization of anaerobic digestion gas production.
- Task 2.2.2—Site Selection and Test Plan: Determine which site the microturbines and enhanced anaerobic systems will be deployed. Prepare an Enhanced Recovery through Optimization of Anaerobic Digestion and Microturbines test plan.

- Task 2.2.3.a—Design Microturbine and Gas Cleaning Systems: Prepare system design and construction drawings.
- Task 2.2.3.b—Design Thermal Hydrolysis and/or Ultrasound Systems: Prepare system design and construction drawings.
- Task 2.2.4.a—Install Microturbine and Gas Cleaning Systems: Install the microturbines and associated gas cleaning systems in accordance with the design and then perform startup and testing of the systems.
- Task 2.2.4.b—Install Thermal Hydrolysis and/or Ultrasound Systems: Install the thermal hydrolysis and/or ultrasound systems in accordance with the design and then perform startup and testing of the systems.
- Task 2.2.5—Collect and Analyze Data for the Microturbine and Gas Cleaning Systems and Optimized Anaerobic Digestion Systems: Use quarterly reports to summarize the data that is collected and the analysis that is performed as part of this task.
- Task 2.2.6—Prepare Final Report for Project 2.2: Prepare a Summary Report that shall include the results of the data and analysis work presented in Task 2.2.5.
- Task 2.2.7—Coordinate with RPAC
- Task 2.2.8—Evaluate Project

Sections 2 and 3 provide additional detail on each task.

1.1.2.1 Project 2.2 Objectives

The objectives of Project 2.2 are to:

- Increase and optimize digester gas production through thermal hydrolysis and ultrasound processes
- Develop and optimize cost-effective gas cleanup systems
- Evaluate and quantify environmental benefits that result from using microturbines at sewage treatment plants
- Evaluate performance and cost during operation so sewage treatment plants have greater certainty of cost and reliability of using microturbines

1.2 Report Organization

This report is organized as follows:

- **Section 1** introduces the Commerce Energy program, provides background information on the Chino Basin, presents an overview of the PIER Renewable Project, and outlines the objectives of this report.
- **Section 2** describes the approach that was taken to complete each of the tasks associated with the Project 2.2.

- **Section 3** provides an overview of the results and project outcomes for each of the tasks associated with this project.
- **Section 4** describes the conclusions and recommendations that were drawn from this project and discusses benefits to the State of California.

1.3 Task 2.2.6 Scope and Deliverables

1.3.1 Scope

The scope for Task 2.2.6 is to prepare a final summary report for Project 2.2. The work statement for Task 2.2.6 lists the following report requirements:

- Prepare a Summary Report that shall include the results of the data and analysis work presented in Task 2.2.5. The Summary Report will also include a table that shows the improvement in the plan's performance after the installation and microturbine and gas cleaning system. The economics of each of the projects will include not only the installation, operation, and maintenance costs, but the value of any environmental benefits achieved. Environmental benefits will include items that can be monetized quite easily such as emissions credits. It will also present other information such as changes in greenhouse gas emissions that can be quantified but not as easily monetized. As with the microturbines and gas cleaning systems, the economics of the anaerobic digestion gas production optimization systems will also be presented.
- The final report will be structured to clearly identify the extent to which the performance objectives are achieved for each project. It will also include a separate section specifically designed to help other sewage treatment plants take advantage of the lessons learned.
- Present the drawings of the microturbine and gas cleaning systems and the anaerobic digestion gas production optimization systems.

1.3.2 Deliverables

The following deliverables were submitted for Project 2.2:

- Outline of the Final Report for Project 2.2
- Draft Enhanced Energy Recovery through Use of Microturbines and Optimization of Anaerobic Digestion Report
- Final Enhanced Energy Recovery through Use of Microturbines and Optimization of Anaerobic Digestion Report and Drawings on microturbine and gas-cleaning systems and anaerobic digestion optimization systems

CHAPTER 2: Project Approach

As discussed in Section 1, the overall goal of Project 2.2 is to increase biogas power generation at wastewater treatment plants. In order to satisfy this goal, a series of ten different tasks were completed (as listed in Section 1). The first seven tasks are summarized in this report. Completion of the last three tasks will follow the submittal of this report. The first seven tasks are listed and described in further detail in the sections below. Additional information about the specific project results and outcomes associated with these tasks is provided in Section 3.

2.1 Task 2.2.1: Technology Review and Process Selection

2.1.1 Task Summary

The purpose of this task was to evaluate and select two sets of processes that could be potentially employed at the sites identified in Project 1.1. The first set of processes to be selected included gas cleaning systems for microturbines. The second set of processes to be selected related to optimization of anaerobic digestion gas production. These two sets of processes were evaluated as part of the *Task 2.2.1 Process Selection Report for Wastewater Treatment Plants* (Process Selection Report) (CH2M HILL, 2003).

2.1.2 Task Approach

2.1.2.1 Gas Cleaning for Power Generation

Biogas is produced in anaerobic digesters at wastewater treatment plants. It consists of a mixture of methane, carbon dioxide, and various contaminants, including water vapor, hydrogen sulfide (H_2S), and siloxanes. The calorific value of biogas typically ranges from 250 to 650 BTU/cubic foot. To run successfully as a fuel in engines or turbines, biogas requires treatment to remove moisture and contaminants. In some cases, blending with natural gas is also needed for consistency of heating value.

In California, there is a move toward microturbines for power generation from biogas, due to their reduced air emissions compared with internal combustion engines. However, field experience indicates that microturbines are even more sensitive to contaminants and moisture than internal combustion engines. Close attention to cleaning and treatment of the biogas prior to use as a fuel has been shown to be necessary for a successful project.

Inland Empire Utilities Agency's (IEUA's) existing microturbine facilities, and their planned expansions, provide a good opportunity to solve specific gas treatment problems while developing experience for packaged system designs that can be used state-wide at other biogas generation facilities. Therefore, it is recommended to install additional gas treatment equipment at the IEUA RP-1 facility.

At IEUA Regional Plant No. 1 (RP-1), the existing Capstone 31-kW microturbines, installed in 2001, provide a convenient and low-cost venue for testing and piloting new biogas treatment technologies. Operations experience already exists on these units, and the units may potentially be retrofitted with gas treatment equipment for testing.

As an alternative, Ingersoll-Rand (IR) offers a 250 kW turbine-generator with a gas treatment equipment package and has expressed a strong desire to participate in a demonstration project for the gas treatment and for its turbine.

Both facilities are designed for 8,000-hour maintenance service intervals. However, most do not experience that, owing primarily to attention required for the gas conditioning upstream of microturbine itself. Up-time can vary considerably, depending mainly on whether gas cleaning equipment is properly anticipated and installed, and on the levels of contamination encountered (i.e., more contamination requires more attention to the removal process, especially for siloxane and hydrogen sulfide removal).

The following biogas treatment measures were considered in the Process Selection Report:

- Drying (moisture removal)
- Hydrogen sulfide removal
- Siloxane removal
- Measures to achieve consistent heating value (fuel blending)

The Process Selection Report identifies several individual treatment systems and combined treatment systems. Ultimately it was decided, that a custom system, capable of removing moisture, hydrogen sulfide, and siloxanes, would be most applicable and beneficial for this project.

2.1.2.2 Enhanced Gas Production

Hydrolysis, or the breakdown of cellular material, is generally held to be the rate limiting step in anaerobic digestion. A typical wastewater treatment plant produces two types of solids, primary solids from the initial sedimentation step, and secondary solids, from the following biological treatment step. The primary solids are usually rapidly putrescible and break down easily. The secondary solids, however, are composed primarily of cellular material from the biological treatment process. These are more difficult to break down in a typical digestion process, as biological breakdown of the cell walls is a slow process and may take up to 8 days. Breakdown, or lysis of these cells releases the organic material contained in the cells, and makes this material available for digestion and conversion to biogas. Therefore, for optimization of gas production, the focus has been on technologies that enhance hydrolysis. There are three primary methods by which hydrolysis can be accomplished:

- Physical—breakdown by mechanical means, such as pressure, temperature and attrition.

- Chemical—breakdown by changing the pH, with acid or alkali addition.

- Biological—biological decomposition, by microbial action. This may be enhanced by control of biological kinetics and pH, or by addition of enzymes and microbes.

Physical hydrolysis processes include thermal hydrolysis, which uses high temperature and pressure, ultrasound, which uses cavitation effects of sound waves, and mechanical grinding technologies such as ball mills. Thermal hydrolysis and ultrasound are technologies that have been gaining increasing interest in the application of improving gas production from digestion of municipal solids and were the two technologies that were focused on in the Process Selection Report.

Chemical hydrolysis is a highly effective method of hydrolysis, however, it is not considered appropriate for digestion of municipal solids. Chemical hydrolysis was not discussed in detail in the Process Selection Report.

Biological hydrolysis processes include addition of enzymes and microbes, usually in a powder form. However, there is very little evidence of any real long term benefits and increases in gas production from these options. Biological hydrolysis was not discussed in detail in the Process Selection Report.

2.2 Task 2.2.2: Site Selection and Test Plan

2.2.1 Task Summary

The purpose of this task was to determine which host sites should be used to install the microturbines and enhanced anaerobic digestion systems that were selected in Task 2.2.1 and then prepare a test plan for the testing of those systems. The *Site Selection and Test Plan* summarizes the results of this evaluation. Specifically, the report discusses the potential site locations for the gas cleaning systems and the ultrasound equipment and then makes recommendations on the best site for each system. This report also presents the test plans for each of these systems.

2.2.2 Task Approach

2.2.2.1 Gas Cleaning for Power Generation

IEUA has microturbines at RP-1, which is the selected site for conducting the biogas cleaning pilot test program. RP-1 is located in Ontario, California, toward the center of the mini-grid and has seven anaerobic digesters, an iron sponge system to remove H_2S, biogas compressors and storage, an energy recovery building, a waste gas burner, and eight microturbines. Six of the seven digesters at RP-1 process the solids from municipal waste. Digester 4 is used to process dairy manure.

RP-1 was selected for the pilot test because it has microturbines and biogas generated using both municipal waste and manure. To control H_2S in the biogas from digestion of municipal waste, iron salts are being added at the headworks to minimize H_2S formation during digestion. The biogas is further treated using an iron sponge. There is no siloxane removal for the internal combustion engines, but carbon filters are used to reduce H_2S levels in the biogas used in microturbines. The biogas produced from manure typically is saturated and has a high H_2S concentration, but is typically free of siloxanes. To reduce H_2S levels in the manure digester biogas, iron salt is added directly to the digesters and the biogas is further treated through an iron sponge.

The following three locations for the proposed gas cleaning systems at RP-1 were considered:

- Next to the existing iron sponges and gas compressors
- North of Digester 4 (the manure digester)
- Close to the energy recovery building, southeast of the digesters

The *Site Selection and Test Plan Report* discusses the pros and cons of each of the potential locations. Section 3.2 summarizes some of this discussion. Ultimately, the Site Selection and Test Plan report recommends installing the gas drying system for moisture removal downstream and east of the existing gas compressors and iron sponges, the biological H_2S removal system north of Digester 4 (so that the technology can be compared to the existing chemical H_2S removal system using ferric chloride), and the packaged siloxane treatment system south-east of the digesters, close to the energy recovery building.

Test Plan for Gas Cleaning Systems. The second portion of this task was to develop a test plan for the gas cleaning systems at IEUA RP-1. This test plan was developed to assist in implementation of a demonstration trial that was conducted to investigate the economic, practical and technical benefits of microturbine gas treatment technologies for removing moisture, siloxane, and H_2S. The test plan lists specific data that should be collected as part of the test, facilities, equipment, and instrumentation that are needed for the test, test parameters and procedures, data analysis procedures, quality assurance procedures, and contingency measures.

The following objectives for this test are discussed in the test plan:

- Obtain the necessary data to determine the contaminant removal efficiency for each of the technologies.

- Obtain the necessary data to determine the cost-effectiveness of operating each of these technologies.

The test plan also suggests a phased schedule for implementation of the various gas treatment systems. The specifics of this test plan can be found in the *Site Selection and Test Plan Report*.

2.2.2.2 Enhanced Gas Production

The City of Riverside is the recommended location for the ultrasound pilot testing program. The City of Riverside Water Quality Control Plant is located at 5950 Acorn Street in Riverside, CA 92504. The point of contact for the testing is Stephen Schultz, Wastewater Systems Manager for the City of Riverside. The wastewater plant has two primary and secondary treatment trains within the same site, referred to as Plant 1 and Plant 2. At present the primary sludge is thickened at each plant and then pumped into a common line to the digesters. The waste activated sludge (WAS) from the two activated sludge plants is sent to one pair of dissolved air flotation thickeners (DAFTs) from where the thickened waste activated sludge (TWAS) is sent to the digesters. The wastewater treatment plant has five existing digesters, of which 3 will be in operation during the test period. These digesters are operated as standard mesophilic digesters at 100°F, and the results from the ultrasound pilot test will be applicable to treatment plants across California.

Three locations for the ultrasound equipment were considered for the City of Riverside Water Quality Control Plant. The evaluation criteria included ease of supply of TWAS to the ultrasound systems, routing of the sonicated solids from each system to the respective digester, piping for bypassing the ultrasound systems in case of a shut down, and electrical hookup for the test equipment. The TWAS feed line to the digesters is buried for most of its length, and is only accessible at the DAFT pump room, or in the digester pump room basement, where the digester feed pipe header and valve systems are located. The three locations considered were:

1. Adjacent to the DAFT pump room
2. On the north side of digesters 1 and 2
3. On the south side of digesters 1 and 2

Having considered three potential locations of the test equipment, and discussed these with the plant staff, it was clear that the third location, on the south side of digesters 1 and 2, would be the best in terms of maintaining access to the plant facilities, minimizing the length of temporary piping and electrical lines, and minimizing potential health and safety issues. This location is discussed in further detail in Section 3.2.

Ultrasound Test Plan. The second portion of this project was to develop a test plan for the ultrasound system at the City of Riverside sewage treatment plant. This test plan was developed to assist in the implementation of a demonstration trial which was conducted to investigate the economic, practical and technical benefits of using ultrasound to increase gas production on existing anaerobic digesters at the City of Riverside Sewage Treatment Plant. The test plan lists specific data that should be collected as part of the test, facilities, equipment, and instrumentation that are needed for the test, test parameters and procedures, data analysis procedures, quality assurance procedures, and contingency measures.

The following objectives for this test are discussed in the test plan:

- Establish robust baseline performance data for the test digesters
- Evaluate performance of two digesters, each with a different ultrasound system
- Evaluate operability of the two ultrasound systems (downtime, energy draw etc.)

In addition to providing objectives and lists of specific data to collect, the test plan also recommended performing the test in four different phases:

1. **Pretest Phase**—This phase was designed to ensure that the data collected during the test will be robust and reliable.

2. **Baseline Phase**—This phase was designed to collect the detailed baseline data so that actual test data could be compared to a baseline performance.

3. **Ultrasound Test Phase**—This phase was designed to collect the actual ultrasound performance data.

4. **Continuation Phase**—This phase was designed to confirm whether improvements seen during the ultrasound testing phase can truly be attributed to the use of the ultrasound equipment.

The specifics of this test plan can be found in the *Site Selection and Test Plan Report*.

2.3 Task 2.2.3.a: Design Gas Cleaning Systems

2.3.1 Task Summary

The purpose of this task was to begin implementation of the gas cleaning systems selected in Task 2.2.1 by preparing a design suitable for the host facility selected in Task 2.2.2. As discussed above, a custom treatment system at RP-1 was recommended.

2.3.2 Task Approach

Activities under Task 2.2.3.a included implementing the system selected above through the preparation of a design suitable for the selected host facility. The Microturbine and Gas Cleaning System Design and Construction Drawings prepared integrated the microturbine, gas cleaning and related equipment including heat recovery into the requirements of IEUA Regional Plant 1. Mechanical, electrical, instrumentation/controls, and site/civil drawings, suitable for construction were prepared.

2.4 Task 2.2.3.b: Design Ultrasound Systems

2.4.1 Task Summary

The purpose of this task was to begin implementation of the ultrasound systems selected in Task 2.2.1 by preparing a design suitable for the host facility selected in Task 2.2.2. Different ultrasound systems and manufacturers are evaluated as part of the Process Selection Report. Two manufacturers, IWE.tec and Sonico were selected to provide ultrasound systems for pilot testing. This section will briefly describe the technologies and the equipment to be provided by each manufacturer.

2.4.2 Task Approach

Activities under Task 2.2.3.b included preparation of Ultrasound System Design and Construction Drawings. This design included equipment specifications and drawings to facilitate installation of the ultrasound optimization equipment in the host facility. The mechanical, electrical, instrumentation/controls, and site/civil drawings needed for field installation were prepared. Prepackaged pilot unit manufacturer's drawings and related information were provided and a site plan for installation was prepared. This task enabled the selected ultrasound systems to be integrated into the City of Riverside Wastewater Treatment Plant (WWTP).

2.5 Task 2.2.4.a: Install Gas Cleaning Systems

2.5.1 Task Summary

The purpose of this task was to install the microturbine and associated gas cleaning systems in accordance with the design prepared in Task 2.2.3.a. Under this task, installation of the microturbine gas cleaning systems was completed in accordance with the design.

2.5.2 Task Approach

This task was accomplished with staff from the host facility (IEUA) as well as vendor and Commerce Energy Team personnel. Installation activities were accomplished in accordance with all local codes and standard practices. Startup and testing of the gas cleaning systems were also undertaken in this task. The final activities completed on this task were the submission to the Energy Commission a letter of notification that the installation was completed and submission to the Energy Commission and the host facility As-Built Drawings for the Installed Microturbine and Gas Cleaning System.

2.6 Task 2.2.4.b: Install Ultrasound Systems

2.6.1 Task Summary

The purpose of this task was to install the ultrasound systems in accordance with the design prepared in Task 2.2.3.b. Under this task, installation activities for the ultrasound systems were completed in accordance with the design completed under Task 2.2.3.b.

2.6.2 Task Approach

The Commerce Energy Team staff worked with staff from the vendors and host facilities to complete installation activities. Startup and testing activities were completed. A letter documenting completion of the installation and the as-built drawings for the installed ultrasound systems was provided to the Energy Commission and the City of Riverside.

2.7 Task 2.2.5: Collect and Analyze Data

2.7.1 Task Summary

The purpose of this task was to collect and analyze data for the following two system types: microturbine and gas cleaning systems and optimized anaerobic digestion systems (e.g., ultrasound).

2.7.2 Task Approach

Data were collected and analyzed per the recommendations of the Test Plan for each project (see the *Site Selection and Test Plan Report*). Information was summarized in the following quarterly reports:

- First Quarterly Data Report: data for the period June 1, 2004, through August 31, 2004
- Second Quarterly Data Report: data for the period September 1, 2004, through November 30, 2004

- Third Quarterly Data Report: data for the period December 1, 2004, through February 28, 2005
- Fourth Quarterly Data Report: data for the period March 1, 2005, through May 31, 2005
- Fifth Quarterly Data Report: data for the period June 1, 2005, through August 31, 2005
- Sixth Quarterly Data Report: data for the period September 1, 2005, through November 30, 2005

CHAPTER 3: Project Outcomes

As discussed in sections 1 and 2, seven tasks were completed for Project 2.2, with the overall goal of increasing biogas power generation at wastewater treatment plants. Section 2 discussed the approach that was taken to complete tasks 2.2.1 through 2.2.6. This section discusses the specific project results and outcomes associated with these tasks and in turn the project objectives. Project objectives and projected outcomes were presented to the Energy Commission at the beginning of the project. Results obtained through the research conducted during the project formulated the actual project outcomes. Table 3-1 shows the relationship between objectives, projected outcomes, actual outcomes, and the associated tasks that were completed in order to satisfy each objective.

Additional discussion regarding the specific outcomes associated with each task is presented below.

3.1 Outcomes of Task 2.2.1: Technology Review and Process Selection

The purpose of Task 2.2.1 was to evaluate and select gas cleaning systems for microturbines and systems that could be used to optimize anaerobic digestion gas production. Information that was collected as part of this evaluation is presented in the Process Selection Report. The recommendations included in that report are summarized in this section.

3.1.1 Gas Cleaning for Power Generation

Two opportunities for improving gas cleaning systems for microturbines were identified for this project. The first opportunity was to install a single, custom, economical process that allows integration into the desired microturbine 8,000-hour service intervals to remove moisture, hydrogen sulfide and siloxanes. The second opportunity was to install a system that would reduce the cost of hydrogen sulfide removal and simplify operation and maintenance.

Components of the recommended custom system are shown in Figure 3-1 and discussed below.

3.1.1.1 Gas Drying and Compression

Biogas from anaerobic digestion naturally has a high concentration of moisture. This has a significant effect on the performance and maintenance of engines and turbines. Drying of biogas is a basic requirement. Typically, the trade-off has been equipment life versus capital cost to implement gas drying. Microturbines, which operate at higher rotational speeds than reciprocating engines, are more sensitive to moisture content. They also require compression of the gas stream, so a combination of cooling and compression is a typical treatment for these systems. The compression system must be sized to the flow rate and pressure requirements of the microturbine(s).

Table 3-1: Project 2.2 Objectives, Outcomes, and Tasks

Objective	Projected Outcome	Actual Outcome	Associated Tasks
Increase and optimize digester gas production through thermal hydrolysis and ultrasound processes.	For the digester gas production improvement processes (thermal hydrolysis and ultrasound), the focus will be on evaluation of the systems, their impact on gas production, and their cost-effectiveness. An evaluation of the digester gas production and quality as well as biosolids reduction rate and dewatering characteristics will be presented. The installation and operating costs for the systems will be established for full-scale facilities. The cost-effectiveness evaluation will include the overall installation and operating cost compared to the benefits of improved gas production and reduced biosolids mass for disposal/reuse. A detailed evaluation and quantification of environmental benefits for each of the systems will also be developed.	The *Task 2.2.1 Process Selection Report for Wastewater Treatment Plants* (Process Selection Report) (CH2M HILL, 2003) concluded that ultrasound has a greater potential for application in Southern California than does thermal hydrolysis. As a result, ultrasound was the focus for this evaluation. IWE.tec and Sonico ultrasound systems were chosen for evaluation. IWE.tec and Sonico systems were designed and then installed at the City of Riverside Wastewater Treatment Plant. Testing of the systems was conducted in accordance with the Test Plan documented in the Task 2.2.2 *Site Selection and Test Plan Report* (CH2M HILL, 2004). Findings were reported in the six quarterly reports, which include summaries of the digester gas production and biosolids reduction and dewatering processes. Installation and operating costs are also summarized in the quarterly reports. Technical, environmental, and economic performance of the ultrasound units are summarized in this final report for Project 2.2.	Task 2.2.1—Process Selection Task 2.2.2—Site Selection and Test Plan Task 2.2.3.b—Design Thermal Hydrolysis and/or Ultrasound Systems Task 2.2.4.b—Install Thermal Hydrolysis and/or Ultrasound Systems Task 2.2.5—Collect and Analyze Data for the Microturbine and Gas Cleaning Systems and Optimized Anaerobic Digestion Systems Task 2.2.6—Prepare Final Report for Project 2.2
Develop and optimize cost-effective gas cleanup systems.	At least three gas cleaning systems will be defined and optimized. It is anticipated that one of these systems will involve hydrogen sulfide removal, gas drying, and siloxane removal. A second system will likely involve gas drying and siloxane removal. A third system, with parameters not yet defined, will also be formulated. The installation and operating costs for each system will be determined for the full project life cycle.	Three gas cleaning systems were designed, installed, and tested at the IEUA RP-1 facility in accordance with the Test Plan. The first system tested included a chiller that had two purposes: moisture removal and siloxane removal. The second system tested was a biological scrubber that was installed to remove H_2S from the gas stream. The scrubber was compared to the current iron sponge technology used at the facility. The third system tested involved using different absorption media (graphite- and polymer-based) for siloxane removal. The installation and operating costs for each system are reported in the quarterly reports.	Task 2.2.1—Process Selection Task 2.2.2—Site Selection and Test Plan Task 2.2.3.a—Design Microturbine and Gas Cleaning Systems Task 2.2.4.a—Install Microturbine and Gas Cleaning Systems Task 2.2.5—Collect and Analyze Data for the Microturbine and Gas Cleaning Systems and Optimized Anaerobic Digestion Systems
Evaluate and quantify environmental benefits that result from using microturbines at sewage treatment plants.	A detailed evaluation and quantification of environmental benefits for each of the systems described above (the gas cleanup systems) will be developed. These will be presented in the context of the Capstone microturbine. A comparison to the existing conditions will be included in this assess-	Technical, environmental, and economic performance of the gas cleaning units are summarized in Section 4 of this final report for Project 2.2. Each of the systems evaluated is compared to the existing gas treatment method (iron sponge).	Task 2.2.5—Collect and Analyze Data for the Microturbine and Gas Cleaning Systems and Optimized Anaerobic Digestion Systems Task 2.2.6—Prepare Final Report for Project 2.2

Table 3-1: Project 2.2 Objectives, Outcomes, and Tasks

Objective	Projected Outcome	Actual Outcome	Associated Tasks
	ment. The expected outcome will be to increase gas production by 10 to 20 percent at an existing wastewater treatment plant, which ranges in size from 1 to 50 million gallons per day (MGD). Also on this project, the Contractor will seek to improve the efficiency and cost-effectiveness of gas cleaning systems used on microturbines, but in this part of the project it may make more sense to test the work at an existing facility rather than install new generation. The expected cumulative generating capacities resulting from this project is expected to range from 60 kW to 1 MW.		
Evaluate performance and cost during operation so sewage treatment plants have greater certainty on cost and reliability of using microturbines.	The results of this evaluation will be documented in a report that evaluates the cost and effectiveness of the various gas cleanup systems for each of the micro-turbines considered. The economics of the systems will be evaluated based on the value of electricity produced and waste heat recovered and used at the sewage treatment plant. Various alternatives will be compared by examining the net present value of different systems and the rate of return based on funds utilized.	Results from pilot testing of the gas systems are summarized in the quarterly reports. The quarterly reports discuss the effectiveness and cost (installation and operation) of each of the gas systems. This final report for Project 2.2 summarizes the economics of each of the systems and compares the net present value of each system.	Task 2.2.5 – Collect and Analyze Data for the Microturbine and Gas Cleaning Systems and Optimized Anaerobic Digestion Systems Task 2.2.6 – Prepare Final Report for Project 2.2

A typical drying system includes chilling and water removal. Compression goes hand-in-hand with drying, as the gas is compressed to saturation conditions, much of the moisture falls out, so that most of the removal happens automatically in the compression cycle. The Process Selection Report recommended incorporating the following gas drying elements into the custom system: compressor, air cooler, water chiller, and gas dryer.

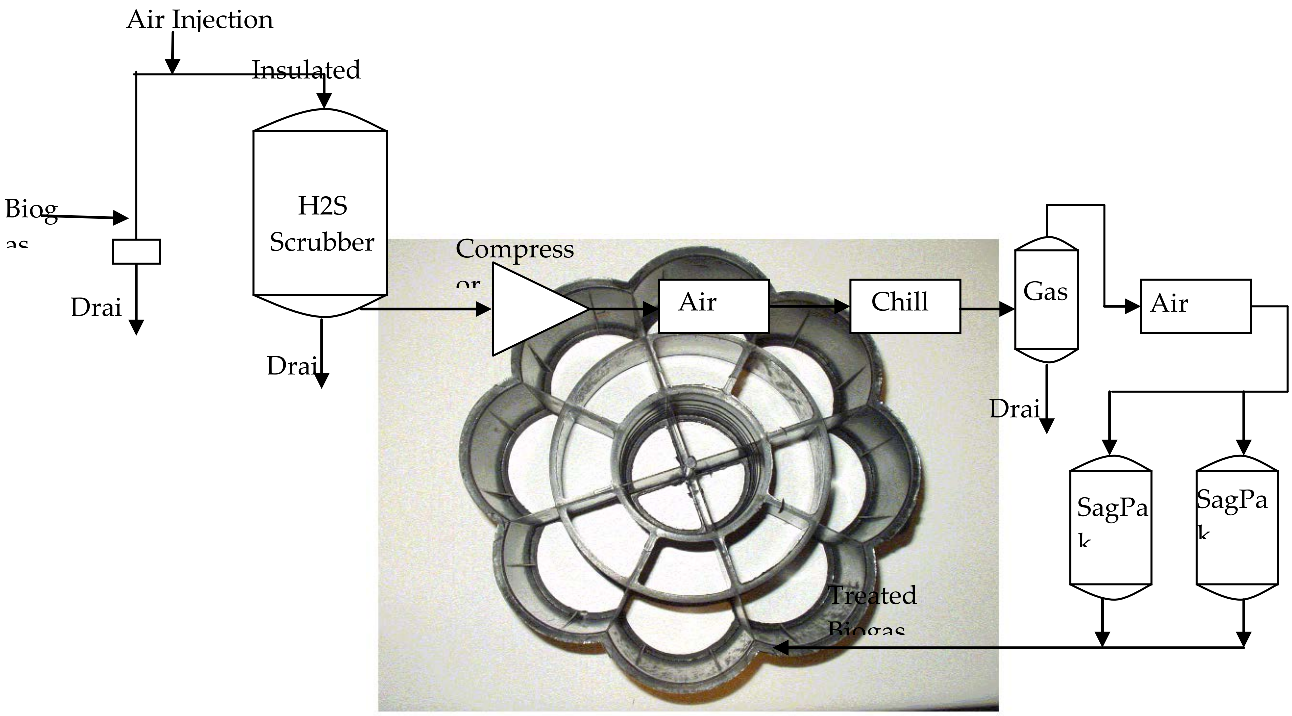
3.1.1.2 H_2S Removal

Hydrogen sulfide (H_2S) is a naturally occurring constituent of sewage treatment biogas. When biogas is used in an engine or turbine, H_2S is released in the exhaust gases. H_2S does not necessarily harm reciprocating engines, but it does cause air pollution when released to the atmosphere, and it affects the construction materials for heat recovery equipment. IEUA employs H_2S removal equipment, which is used primarily for reduction of air emissions. Also, H_2S can combine with residual moisture in the gas stream to form sulfuric acid, which will damage downstream equipment. Microturbines, which are more sensitive than engines to corrosion on internal parts, require a higher level of treatment than reciprocating engines. Ingersoll-Rand requires the hydrogen sulfide content of the fuel gas to be at or below 25 ppm for use in their microturbines.

Biological treatment of biogas is one method of H_2S removal. This method has become common at Danish biogas facilities and was the method that was recommended in the Process Selection Report.

In a biological gas treatment system, the digester biogas is transferred to a separate H_2S removal unit. The unit contains a tank filled with a bed of plastic or ceramic filter chips that act as bacteria-growing media. Figure 3-2 shows a filter chip that has been used in this application.

Figure 3-1: Custom Gas Treatment System Concept Flow Diagram



A mixture of water and nutrient solution—nitrogen, phosphorus, potassium (N,P,K)—with micro-nutrients; animal manure or digestate) is added to the tank, and sprayed out over the chips. When the system is started it is advantageous to add seed material that already contains H_2S removing bacteria. This might be manure, digestate, or wastewater treatment plant sludge.

Figure 3-2: Typical Filter Chip Used in Biological Gas Treatment System

The chips increase the reactive surface between biogas, air, water, nutrients and H_2S removing bacteria. Because biological H_2S removal creates sulfuric acid, there is the potential for high corrosion rates on the equipment. Thus the H_2S removal unit, valves, pumps and pipes must be constructed of plastic, stainless steel or equivalent material, which is resistant to both acid and leaching.

Because the nutrient spray cools the biogas, water is removed by condensation, which removes most of the ammonia (NH_3) and about 15 to 25 percent of the H_2S. Existing biogas cleaning units show that biological H_2S removal easily reduces the H_2S content by 90 to 99 percent, so that typical H_2S concentrations in the 2,000 ppm range before treatment can be reduced to as low as 20 ppm after treatment.

3.1.1.3 Siloxane Removal

Siloxanes form a class of silicon-containing compounds derived from personal care and industrial products that are commonly encountered in biogas from wastewater treatment plants. They are hydrophobic, having little solubility in water, but are miscible in most oils. Siloxanes have unique properties of being fairly volatile, despite their high molecular weight, yet stable against degradation except when burned in biogas, which process results in silica oxide deposits on surfaces exposed to combustion products. Common levels of total siloxanes can vary considerably, depending on feed to the WWTP or landfill, but are generally found in the range of 2 to 5 ppm.

This contaminant has become increasingly significant over the past 5 to 10 years, as more man-made silicone compounds enter municipal waste streams. Combustion of biogas containing siloxane tends to leave deposits of silica oxide residual on internal engine combustion surfaces, impairing engine performance and significantly increasing system maintenance. Historically, siloxane removal has not been commonly applied for reciprocating engines, resulting in shortened life span and increased maintenance intervals. In the case of microturbines, the silica oxide residual material can be extremely erosive on the turbine blades, so that siloxane removal is critical for that application.

Activated carbon, virgin or regenerated, is the most common method of removing siloxanes today along with refrigeration and liquid absorption. Technologies include:

- Regenerable Graphite-Based Activated Carbon—Applied Filter Technology, Inc.
- Regenerable Resins—Undefined Vendor
- Cyclic Refrigeration and AC Carbon Polishing—Pioneer Air System, Inc.
- Liquid Absorption—Selexol, Dow Chemical, Europe

For these technologies siloxane is adsorbed into a carbon bed, and then the carbon bed is disposed when its effectiveness ends. This results in solids disposal costs. New technologies being investigated include refrigerating the gas to condense out the siloxane, adsorbing the siloxane into a carbon bed that can be regenerated in-situ with steam, and adsorbing into resin beads that can be regenerated in situ with steam or microwaves. The Process Selection Report recommended incorporating the following siloxane removal components into the custom system: a chiller (used primarily for moisture removal, but also assisted in siloxane removal).

The new technologies recommended for further study and pilot are regenerable carbon, graphite, and resin beds. The complexities of regeneration make these technologies practical only in larger applications. These newer technologies generate a small amount of liquid waste. On very small applications, it is probably better to simply dispose of the carbon as is currently done.

3.1.2 Enhanced Gas Production

Having reviewed the potential of thermal hydrolysis and ultrasound for optimization of gas production at municipal treatment plants, and the state of the U.S. market, it appears that ultrasound has a greater potential for application in southern California.

Ultrasound technology for improved anaerobic digestion was tested at laboratory scale as early as the 1960's. However, at that time, ultrasound generating technology was not sufficiently developed to provide a process that could cost-effectively be implemented at full-scale. In the last five years, advances in ultrasound equipment have generated renewed interest in this technology for hydrolysis of municipal solids. The technology provides an easy retrofit option for existing wastewater treatment plants, and has a relatively low cost compared with options such as thermal hydrolysis. The simple installation and operation of this technology make it particularly attractive as a potentially cost-effective method for optimizing gas production at municipal plants.

There are three primary suppliers with systems developed for municipal applications, and these suppliers are continuing to develop and optimize their equipment to improve cost-effectiveness. Most of the work to date has been conducted in Europe, and there is a need to develop this technology for application in the United States.

Two of the suppliers, IWE.tec and Sonico, are making a number of developments with ultrasound systems, which could potentially make this technology even more cost-effective. These systems have not been implemented at full-scale installations, and no work has been done at typical wastewater plants in the U.S. All three of the ultrasound vendors have very different approaches and their systems have different operating parameters, which make direct comparison on paper very difficult. All these factors support the need to conduct testing on the new units being developed, at the same test site, to develop a better understanding of the available systems and their actual benefits for implementation in California to optimize gas production. The Process Selection Report recommends testing the IWE.tec and Sonico ultrasound systems for this project.

3.2 Outcomes of Task 2.2.2: Site Selection and Test Plan

The purpose of Task 2.2.2 was to determine the best sites at which to deploy the technologies and processes for the gas cleaning and enhanced anaerobic digestion that were selected in Task 2.2.1 and to develop expanded process flow diagrams that further define the selected processes and show integration into the selected host facility and test plans for the new systems. Information that was collected as part of this task is presented in the *Site Selection and Test Plan Report*. The recommendations included in that report are summarized in this section.

3.2.1 Gas Cleaning for Power Generation

3.2.1.1 Site Selection

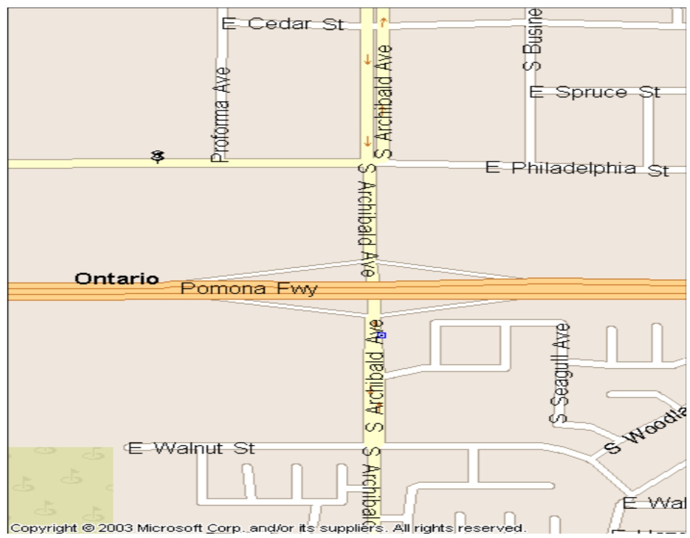
As discussed in Section 2.2, the IEUA RP-1 facility was selected to conduct the biogas cleaning pilot test program. The selected site, RP-1, is located at 2450 E. Philadelphia, Ontario, CA, 91761. The main contacts for the Biogas Cleaning Pilot Test program are listed in Table 3-3. Figure 3-3 contains a location map and a vicinity map showing RP-1's location.

Figure 3-4 contains the overall plant layout for RP-1. This layout shows the location of the existing digesters (northwest quadrant of the site); iron sponges, gas compressors and gas storage (southeast of the digesters) and microturbines (north of the Control Building).

Table 3-3: Project Team Members Contact Information

Name	Company	Address	Telephone	Fax	Email
Eliza Jane Whitman	IEUA	6075 Kimball Ave Chino, CA 91710	909-993-1685	909-357-3884	Ewhitman@ieua.org
Ryan Gross			909-993-1699		rgross@ieua.org
Bill Kitto	CH2M HILL	2020 SW Fourth Ave. Suite 300 Portland, OR 97201	503-872-4427	503-736-2000	Bkitto@ch2m.com
Fred Soroushian	CH2M HILL	3 Hutton Centre Dr., Suite 200, Santa Ana, CA 91707	714-435-6232	714-424-6232	Fsoroush@ch2m.com
Carmen Quan			714-435-6117	714-424-2063	Cquan@ch2m.com

Location Map



Vicinity Map

Figure 3-3: RP-1 Location and Vicinity Map

The *Site Selection and Test Plan Report* discussed the three potential sites for locating the gas cleaning pilot equipment at RP-1. Figure 3-5 shows these sites which are identified as A, B and C.

Site A is located next to the existing iron sponges and gas compressors. This site was recommended for the gas drying system due to its proximity to the existing iron sponges and gas compressors. The main biogas header is buried west of the Energy Recovery Building and becomes exposed (above ground) south of the iron sponges. The gas compressors are located only a few feet north of the iron sponges and the exposed main biogas header with low levels of H_2S and high pressure is located East of the compressors and easily available for tapping and feeding the gas drying pilot test equipment.

Site B is located north of Digester 4 (the manure digester). This location was recommended for installation of the H_2S removal pilot test equipment to test the H_2S removal efficiency. This location was recommended because of its numerous advantages. One advantage is that Digester 4 is isolated from the H_2S pretreatment system at RP-1, which consists of injecting ferric chloride at the Headworks. The H_2S pretreatment is required to reduce the content of H_2S in the biogas to comply with the emissions established by the South Coast Air Quality Management District (SCAQMD). Digester 4 has a dedicated ferric chloride injection system that can be turned on and off without affecting the rest of the biogas quality. Another advantage is that the biogas produced in Digester 4 is from 100 percent manure digestion and contains high H_2S content (once the iron salt addition to the digester is stopped).

Site C is located close to the energy recovery building, south-east of the digesters. This site was recommended for installing the packaged siloxane treatment system. This location was recommended because the existing biogas header feeding the existing microturbines was located near this site and could be isolated from the existing system to allow operation of the existing microturbines with the cleaned biogas from the packaged system.

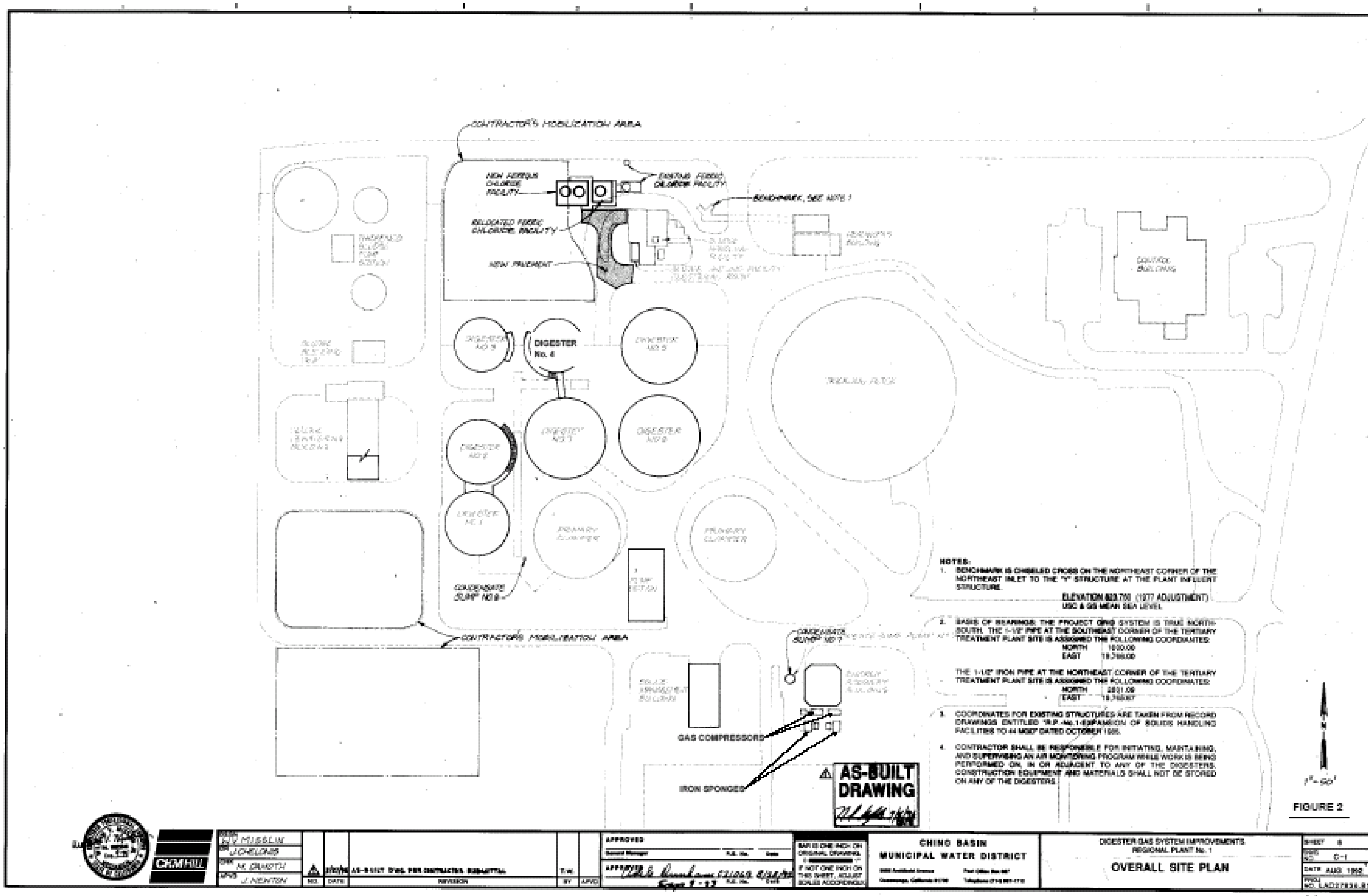


Figure 3-4: Plant Layout for IEUA RP-1 Facility

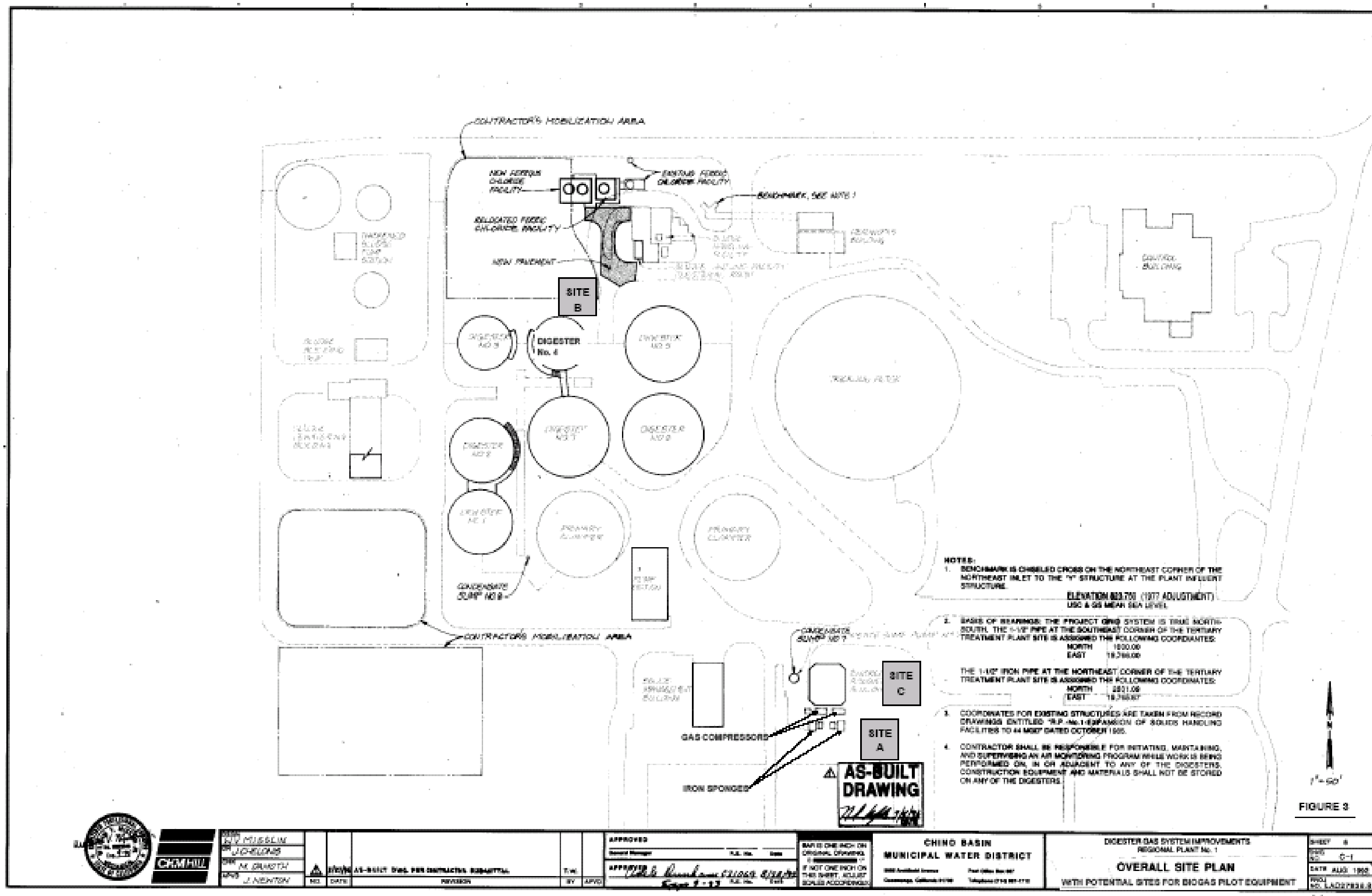


Figure 3-5: Potential Sites for Locating Test Equipment

3.2.1.2 Expanded Process Flow Diagram

The *Site Selection and Test Plan Report* included expanded process flow diagrams for each of the gas cleaning systems. Figures 3-6 and 3-7 contain the process flow diagram for the gas drying system and biological H_2S removal system, respectively. These diagrams include the major components and instrumentation required for each of pilot test units. Figure 3-8 contains the process flow diagram for the package system.

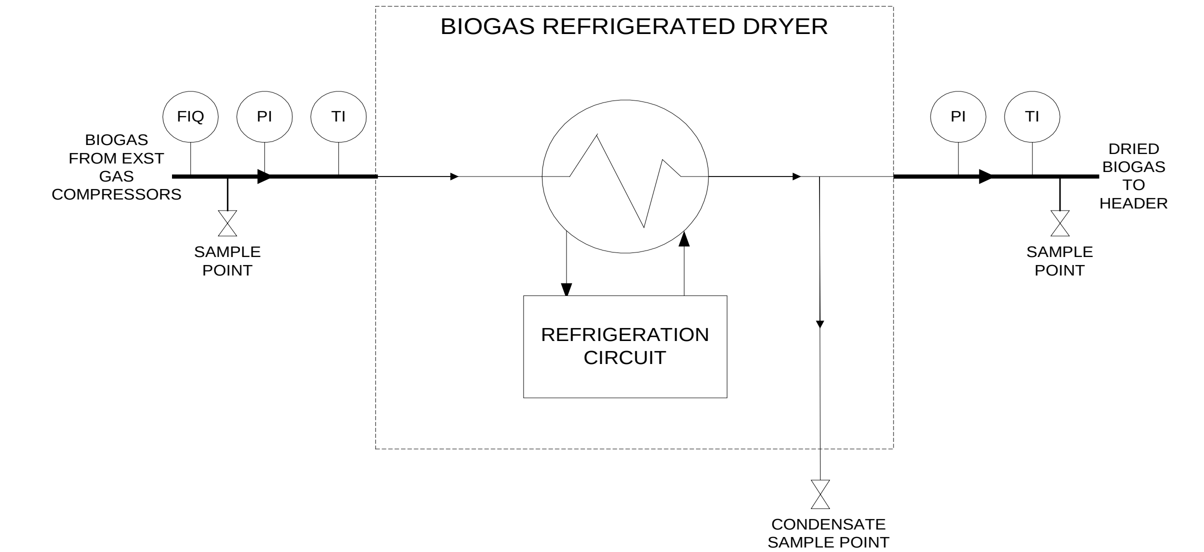


Figure 3-6: Process Flow Diagram for Biogas Drying System

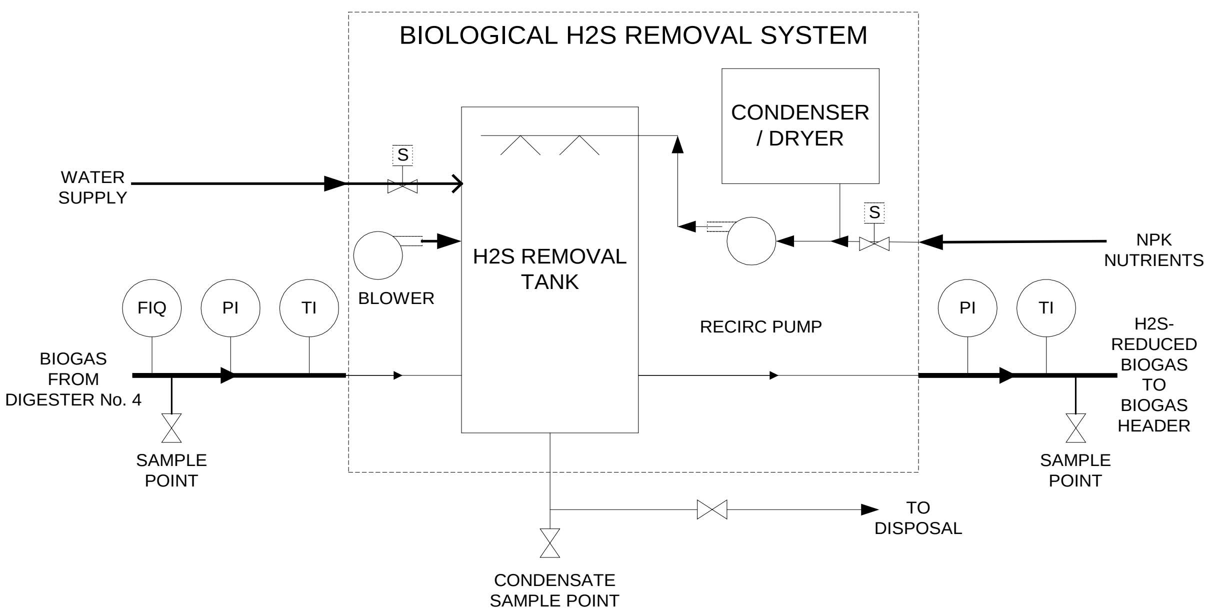


Figure 3-7: Process Flow Diagram for Biological H_2S Removal System

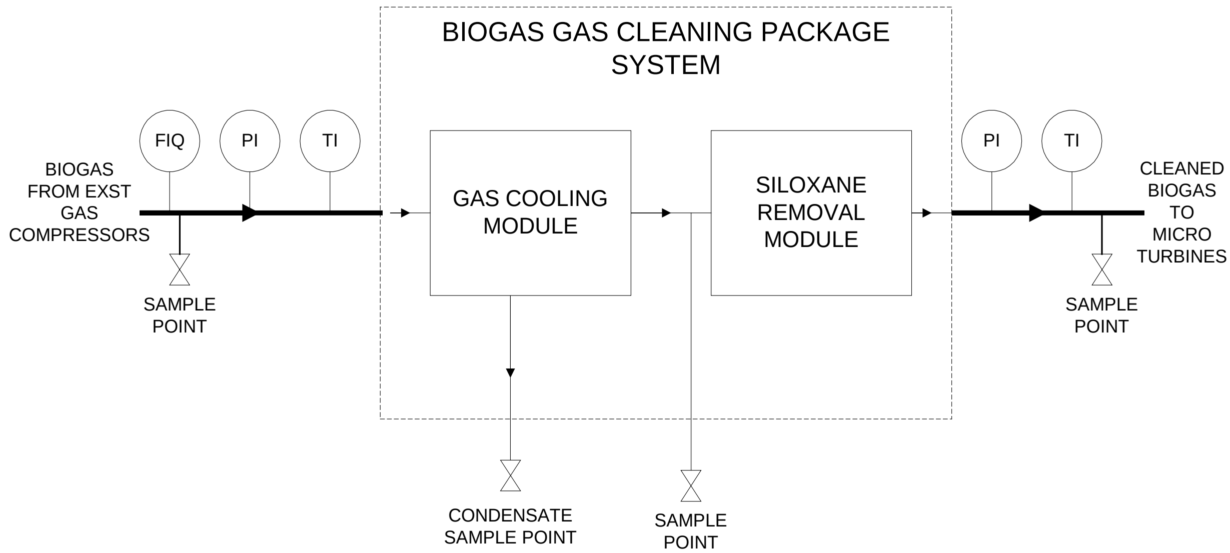


Figure 3-8: Process Flow Diagram for Biogas Cleaning Package System

3.2.1.3 Test Plan

Once site selection was completed a test plan was developed for the gas cleaning systems at IEUA RP-1. This test plan was developed to assist in implementation of a demonstration trial that was conducted to investigate the economic, practical and technical benefits of microturbine gas treatment technologies for removing moisture, siloxane and H_2S. The detailed test plan is included in the *Site Selection and Test Plan Report*. This section summarizes its contents.

The test plan lists the types of data that are needed in order to satisfy the two main test objectives for this pilot program: 1) Obtain the necessary data to determine the contaminant removal efficiency for each of the technologies. 2) Obtain the necessary data to determine the cost-effectiveness of operating each of these technologies. The test plan also lists the equipment and system design elements needed to collect this data.

Table 3-3 contains a summary of the recommended sample collection, tests, data monitoring, data recording, and their schedule.

Table 3-3: Sampling Plan

Sample/Parameter Monitored	Test	Frequency
Gas Drying System		
Biogas upstream of equipment	Moisture/siloxane/VOCs	Biweekly for months 1&2, weekly for month 3
Biogas downstream of equipment	Moisture/siloxane/VOCs	Biweekly for months 1&2, weekly for month 3
Temperature	--	Once a day
Pressure	--	Once a day
Flow	--	Once a day
System power consumption	--	Once a day
Condensate	Volume and temperature	Once a day
Condensate	Composition (VOC, NH3-N, total sulfur, TS, TDS & pH)	Once a month
Siloxane Sagpack System		
Biogas downstream of HOX unit	Moisture/siloxane/VOCs	Biweekly for months 1&2, weekly for month 3
Biogas downstream of Graphite unit	Moisture/siloxane/VOCs	Biweekly for months 1&2, weekly for month 3
Temperature	--	Once a day
Pressure	--	Once a day
Flow	--	Once a day
Biological H_2S Removal System		
Biogas upstream of equipment	Reduced sulfur compound	Once a week
Biogas downstream of equipment	Reduced sulfur compound	Once a week
Temperature	--	Once a day
Pressure	--	Once a day
Flow	--	Once a day
System power consumption	--	Once a day
Scrubber overflow	Volume and temperature	Once a day
	Composition (VOC, NH3-N, total sulfur, TS, TDS and pH)	Once a week

Data analysis procedures, quality assurance procedures, and contingency measures for the pilot test are listed in the test plan.

Table 3-4 summarizes the schedule outlined in the test plan for the different technologies and corresponding phases of the pilot test.

Table 3-4: Microturbine Gas Cleaning Test Schedule

Phase	Duration	Date
Pretest Phase (all pilot technologies)	1 month	March 2004
Baseline Phase for Biological H_2S Removal	18 months	April 2004 – September 2005
Biological H_2S Removal Phase	3 months	October 2005 – December 2005
Gas Drying and Package System Phase[1]	2 months	November 2005 – December 2005

[1] Baseline and technology phase testing for these technologies will be done concurrently. Continuation phase not required for any of these technologies.

The specifics of this test plan can be found in the *Site Selection and Test Plan Report*.

3.2.2 Enhanced Gas Production

3.2.2.1 Site Selection

As discussed in Section 2.2, the City of Riverside is the recommended location for the ultrasound pilot testing program. The City of Riverside Water Quality Control Plant is located at 5950 Acorn Street in Riverside, CA 92504.

The City of Riverside process schematic is shown in Figure 3-9, and the plant layout is shown in Figure 3-10.

Three locations of the ultrasound equipment were considered in the site selection process. The evaluation criteria included ease of supply of TWAS to the ultrasound systems, routing of the sonicated solids from each system to the respective digester, piping for bypassing the ultrasound systems in case of a shut down, and electrical hookup for the test equipment. The TWAS feed line to the digesters is buried for most of its length, and is only accessible at the DAFT pump room, or in the digester pump room basement, where the digester feed pipe header and valve systems are located. The three locations considered were:

1. Adjacent to the DAFT pump room
2. On the north side of digesters 1 and 2
3. On the south side of digesters 1 and 2

The location next to the DAFTs provided easy access to the feed TWAS line, but provided some complications as this would require routing of multiple temporary pipe lines to convey sonicated TWAS from each ultrasound system to the respective digesters, as well as bypass lines, across an on-site roadway that plant staff would need to use. This location significantly increased the total pipe length that would be required.

Location of the test equipment on the north side of the digesters was also considered. At this location, a single TWAS feed line could be installed from the DAFT pump room to the equipment, which would reduce the pipe length and access issues associated with the first location. Alternatively, the TWAS feed to the test equipment could be connected to a T-section on the feed header in the digester pump room basement. This avoided having to run lines across the access road, but the line from the pump room basement required routing it up the main access staircase, which could cause a potential safety issue for plant staff.

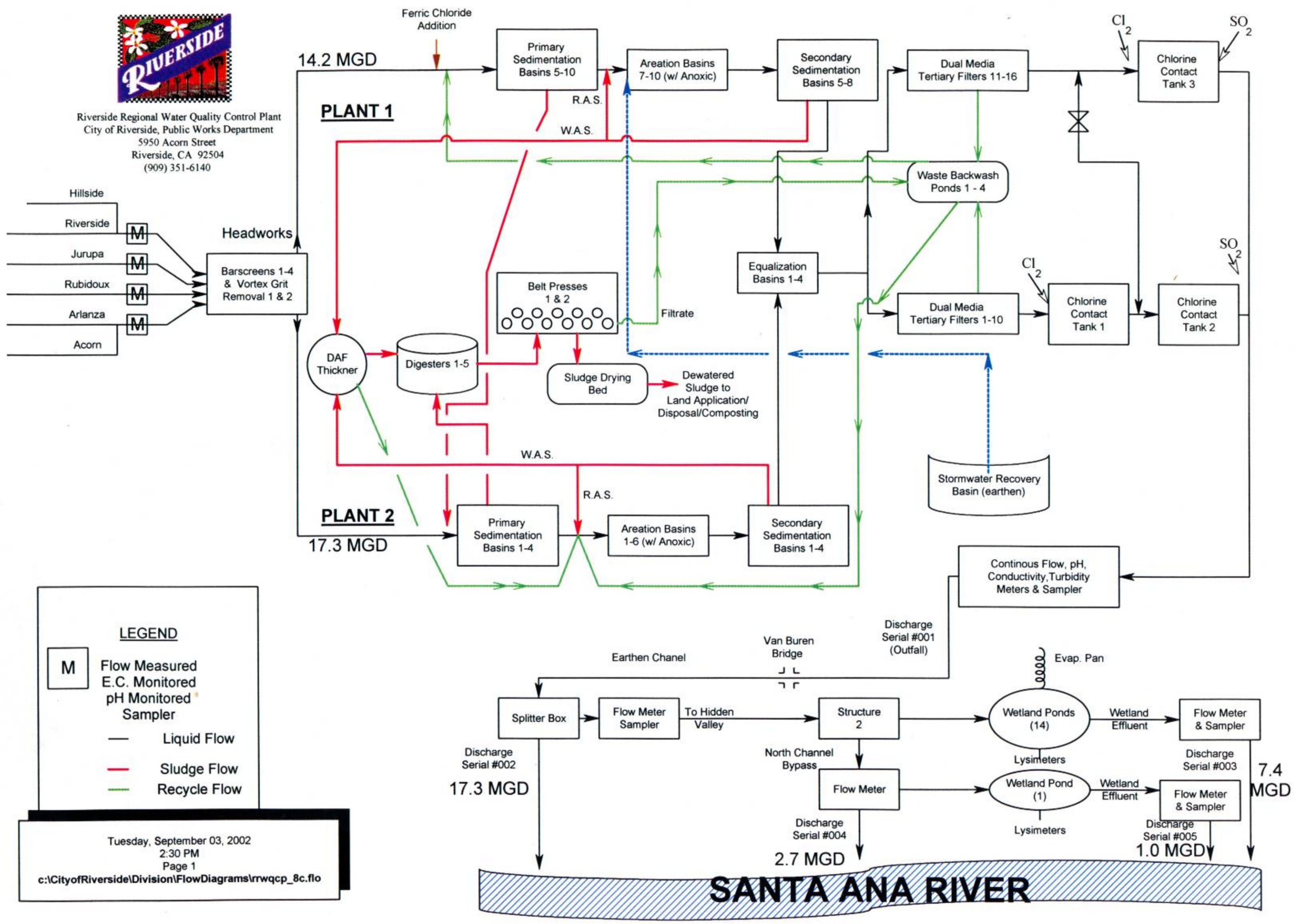


Figure 3-9: City of Riverside Process Schematic

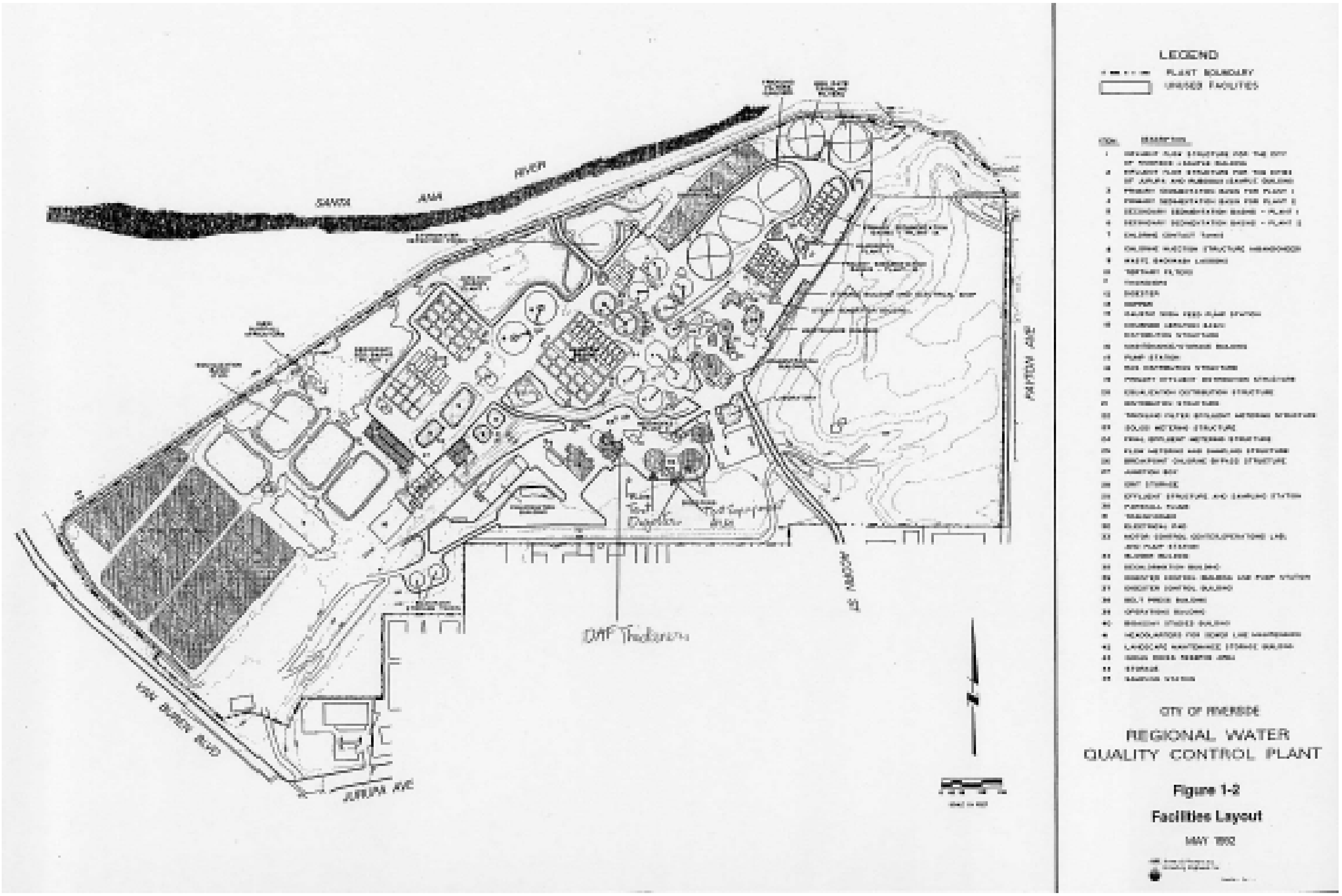


Figure 3-10: City of Riverside Sewage Plant Layout

The sonicated TWAS from the test equipment to the digesters could be routed into the external digester mixing lines on the north side of the digesters. However, electrical connections would have to be routed from a control room on the opposite side of an access road.

Location of the test equipment on south side of the digesters was also considered. There is an existing electrical control room adjacent to the digester pump room on this side, which has spare capacity and could accommodate electrical needs of the test equipment. The TWAS feed to the test equipment could be accessed at the same T-connection in the basement that was considered for the above location. However, by locating the equipment on the south side, the line could be run up an existing ladder, rather than the main access stairway, and would not be a safety concern. There are mixing line access points on the external digester walls on the south side that could be used for routing the sonicated TWAS into the digesters.

The third location, on the south side of digesters 1 and 2, was recommended in the Task 2.2.2 *Site Selection Report* (CH2M HILL, 2004). This location was the best in terms of maintaining access to the plant facilities, minimizing the length of temporary piping and electrical lines, and minimizing potential health and safety issues.

Expanded Process Flow Diagram. The *Site Selection and Test Plan Report* included an expanded process flow diagram for the two ultrasound systems (Sonico and IWE.tec). Figure 3-11 includes the major components and instrumentation required for each of pilot test units.

Test Plan. Once site selection was completed a test plan was developed for testing the two ultrasound systems side-by-side at the City of Riverside sewage treatment plant. This test plan was developed to assist in the implementation of a demonstration trial which was conducted to investigate the economic, practical and technical benefits of using ultrasound to increase gas production on existing anaerobic digesters at the City of Riverside Sewage Treatment Plant.

The test plan lists the types of data that are needed in order to successfully satisfy the following test objectives for this pilot program: (1) Establish robust baseline performance data for the test digesters; (2) Evaluate performance of two digesters, each with a different ultrasound system; (3) Evaluate operability of the two ultrasound systems (for example, downtime, energy draw). The test plan also lists the equipment and system design elements needed to collect these data.

Tables 3-5 and 3-6 summarize the recommended sample collection, tests, data monitoring, data recording, and schedule.

During the phase when the ultrasound systems are on line, the testing described above for the baseline period will be continued. In addition, weekly tests will be conducted for the following additional parameters:

- COD, soluble COD, and viscosity in and out of each ultrasound system

- Microscope analyses for filaments in and out of each ultrasound system

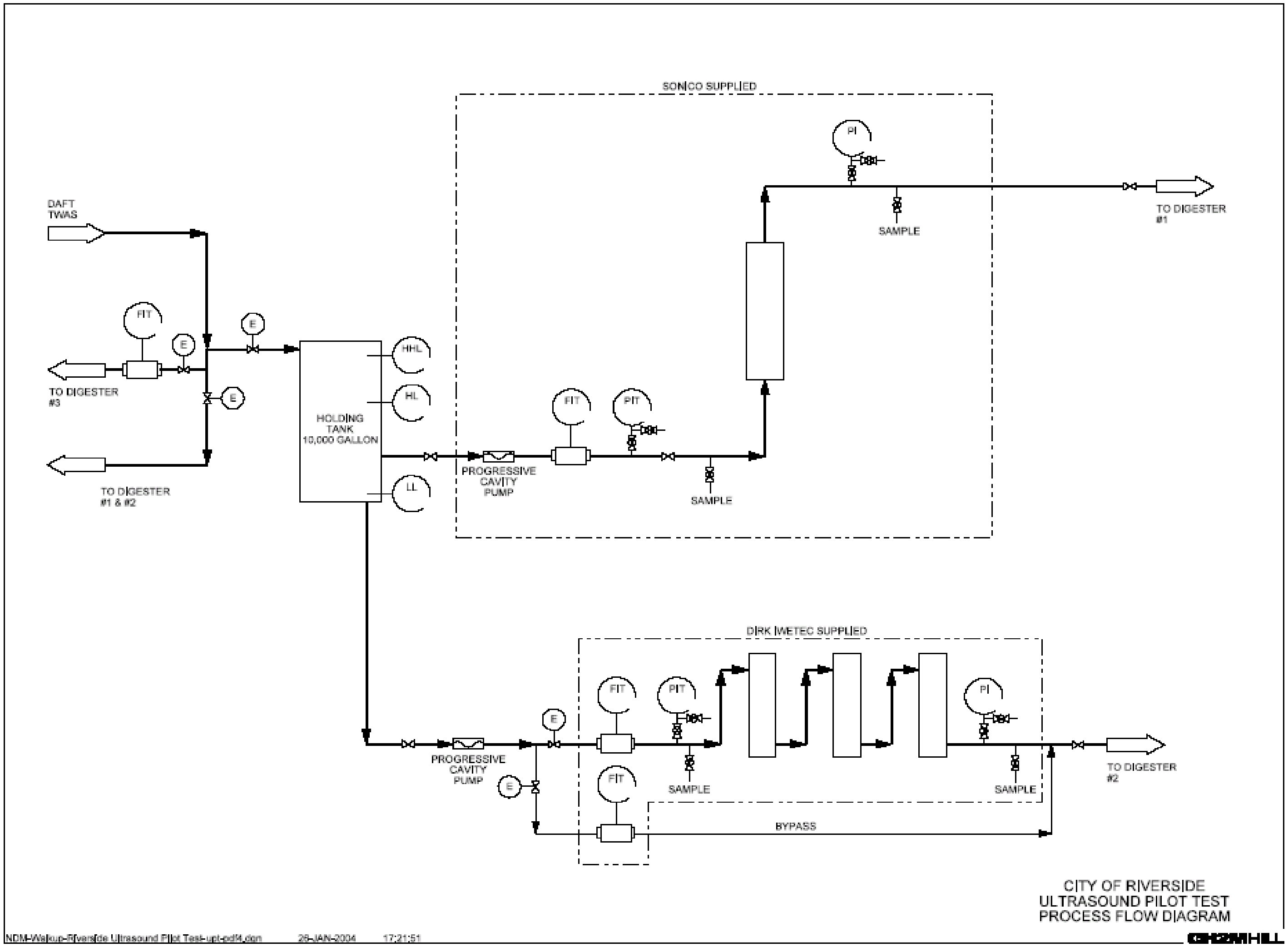


Figure 3-11: Expanded Process Flow Diagram for Ultrasound Pilot Test

Table 3-5: Baseline Solids Handling Data Collection

Parameter	Primary Sludge To Each Digester	TWAS To Each Digester	Digested Sludge From Each Digester	Dewatered Cake[1]	Frequency
Daily Flow (mgd)	√	√	√[2]		Daily
Quantity (wtpd)				√	Daily
TS (%)	√	√	√[2]	√	3 x week
VS (%)	√	√	√[2]	√	3 x week
Alkalinity (mg/L)	√	√	√		3 x week
pH	√	√	√		3 x week
Viscosity		√	√		1 x month
VFA (mg/L)	√	√	√		3 x week
Ammonia (mg/L)				√	3 x week
Nitrate (mg/L)				√	3 x week
TKN (mg/L)	√	√	√	√	3 x week
Sulfate (mg/L)	√	√	√		3 x week
Temperature (ºF)			√		Daily
Iron Salts (mg/L)	√		√		Daily
Polymer (lb/ton)	√	√		√	Daily
Capture rate (%)				√	Daily
Operation (hr/d)				√	Daily
# of Duty Units				√	Daily

[1] Conduct 1 week of more intensive dewatering tests to characterize dewatering variability between each digester.

[2] If bottom sludge is withdrawn from the digesters, the volume and solids should be recorded.

Table 3-6: Baseline Data Collection for Biogas and Co-gen System:

Parameter	Digester Gas from each Digester	Landfill Gas	Natural Gas	Total (entire Co-gen)	Frequency
Daily Flow (scfd)	√	√	√	√	daily
Methane (%)	√	√	√	√	weekly
H_2S (ppm)	√	√	√	√	weekly
BTU	√	√	√	√	End of each phase
Daily electricity (kW)	√	√	√	√	√
Daily amount Flared (scfd)	√	√			

Table 3-6: Baseline Data Collection for Biogas and Co-gen System:

Parameter	Digester Gas from each Digester	Landfill Gas	Natural Gas	Total (entire Co-gen)	Frequency

Assistance from City of Riverside plant staff will be required to check operation of the ultrasound systems. Both units will be provided with control panels for automated operation. A log sheet will be provided for once daily monitoring of the systems, which will include:

- Electricity used by each ultrasound system
- Daily recording of line pressure in and out of the ultrasound systems
- Number of units operational
- Power draw for each unit
- Flow rate through the two ultrasound systems

Data analysis procedures, quality assurance procedures, and contingency measures for the pilot test are listed in the test plan.

The test will be conducted in four phases, briefly described below.

1. **Pretest Phase—**During this phase, a number of checks will be carried out at the City of Riverside sewage treatment plant, to ensure that the data collected during the test will be robust and reliable. This includes calibration of all flow meters (sludge flows and gas flows), evaluation of mixing systems on the test digesters, tracer tests to determine digester operating volume, and collection of plant data for the past year.

2. **Baseline Phase**—During the first three months of the test, detailed baseline data will be collected with the newly calibrated instrumentation and following the test procedures described in the *Site Selection and Test Plan Report*.

3. **Ultrasound Test Phase**—Once the two ultrasound systems are installed, the ultrasound systems and digesters' performance will be monitored, as per the test procedures described in the *Site Selection and Test Plan Report*.

4. **Continuation Phase**—After the ultrasound systems have been shut down at the end of phase three, the digesters will continue to be monitored for another two to three months, to follow the change in digester performance back to the baseline. This confirms that improvements seen during the ultrasound testing phase can truly be attributed to the use of the equipment.

Table 3-7 summarizes the schedule outlined in the test plan for the pilot test.

Table 3-7: Enhanced Anaerobic Digestion Test Schedule

Phase	Duration	Date

Table 3-7: Enhanced Anaerobic Digestion Test Schedule

Phase	Duration	Date
Pretest Phase	1 month	February 2004
Baseline Phase	3 months	March – May 2004
Ultrasound Phase	6 months	June – Nov 2004
Continuation Phase	3 months	Dec 2004 – Feb 2005

The specifics of this test plan can be found in the *Site Selection and Test Plan Report*.

3.3 Outcomes of Task 2.2.3.a: Design Gas Cleaning Systems

The purpose of Task 2.2.3.a was to perform design activities for the process and sites selected in Tasks 2.2.1 and Task 2.2.2. Under Task 2.2.3.a, design activities were completed for gas cleaning systems at IEUA Regional Plant No. 1.

Activities under Task 2.2.3.a included implementing the system selected above through the preparation of a design suitable for the selected host facility. The Microturbine and Gas Cleaning System Design and Construction Drawings prepared integrated the microturbine, gas cleaning and related equipment including heat recovery into the requirements of IEUA Regional Plant No. 1. Mechanical, electrical, instrumentation/controls, and site/civil drawings, suitable for construction were prepared. The drawings included in the gas cleaning drawing package are listed in Table 3-8.

Table 3-8: Digester Gas Cleaning System at IEUA RP-1 Drawing Package

Drawing No.	Drawing Title
T-1	Cover sheet and Drawing Index
G-1	Mechanical Legend
DG-1	Digester Gas Yard Piping Plan
DG-2	Digester No. 3 and No. 4 Cover Digester Gas Piping Plan
DG-3	Biological H_2S Removal System Piping Plan and Sections—1
DG-4	Gas Compression and Blending Area Piping Plan
DG-5	Microturbine Piping Plan and Sections
DG-6	Biological H_2S Removal System Piping Plan and Sections—2
E-1	Electrical Legend—1
E-2	Electrical Legend—2
E-3	Gas Compression and Blending Area Electrical Plan
E-4	Digester Gas Electrical Plan
E-5	Chiller- Single Line Diagram and Schematic
E-6	H_2S Scrubber—Single Line Diagram and Schematic

Table 3-8: Digester Gas Cleaning System at IEUA RP-1 Drawing Package

Drawing No.	Drawing Title
E-7	Biological H_2S Removal System Electrical Plan
I-1	Not Used
I-2	Control Diagrams—1
F-0	Process Flow Diagram Legend and Symbols
F-1	Process Flow Diagram Digester Gas System
F-2	Process Flow Diagram Biological H_2S Removal System
F-3	Process Flow Diagram Digester Gas System
F-4	Process Flow Diagram Chiller
F-5	Process Flow Diagram Digester Gas System
F-6	Process Flow Diagram Digested Sludge to Dewatering

The existing treatment process at RP-1 includes ferric chloride injection at the headworks to control the H_2S concentration in the biogas produced at anaerobic digesters No. 1 through 3 and 5 through 7. The amount of H_2S in the biogas from these digesters is less than 100 ppm. Ferric chloride is directly injected into Digester 4 to maintain the amount of H_2S in the biogas at an average of 60 ppm. After the biogas is collected from all the digesters, it is treated with iron sponges to further reduce the amount of H_2S to approximately 5 ppm. The biogas compressors are located downstream of the iron sponges and increase the biogas pressure to 40 psig before it is stored in the biogas storage system. From the storage system the biogas is distributed to the engine generators, boilers and the microturbines.

The proposed Gas Cleaning Pilot System consists of testing technologies that have the potential to remove moisture, siloxanes and H_2S; but that are neither being used in the USA nor have been applied at the scale needed for microturbine gas treatment. These technologies are gas drying, biological H_2S removal system and a package system for siloxane treatment. Below are the descriptions of the equipment for the proposed Gas Cleaning Pilot System that were incorporated into the design.

3.3.1 Gas Drying

The selected technology for pilot testing is a refrigerated dryer for moisture removal and its effects on siloxane removal through the condensate.

The refrigerated dryer system is skid mounted, suitable to handle biogas and consists of a refrigeration unit, a vertical heat exchanger and a control. The heat exchanger module utilizes a plate-to-plate pre-cooler that lowers the refrigeration energy requirements. This unit performs three functions, gas chilling, moisture separation, and condensate removal. The unit is suitable to handle pressurized biogas between 20 and 300 psig. It handles biogas with an inlet temperature of 150°F and cools it to 40°F dew point. The pressure drop across the unit is 2 psig. The unit has a Class 1, Division 1 classification. The control panel is explosion-proof rated.

The refrigerated dryer for this pilot test program will be sized to treat 50 scfm of biogas. This is enough biogas to run four of the existing 30-kW microturbines (12 scfm per microturbine).

3.3.1.1 H_2S Removal

The H_2S found in biogas can be removed through a biological process by bacteria. The bacteria in this process oxidize the sulfide to produce both elementary sulfur and sulfur acid. The bacteria live naturally in nearly all substrates (soil, water, sludge and manure) and require nutrients, oxygen/air, and humidity to live. The biological activity is temperature dependent, and this process works more efficiently at a temperature of approximately 35°C (95°F).

In this process, the biogas flows from the digester to the H_2S removal tank, which is partially filled with plastic or ceramic filter chips as growing media for the bacteria. The filter chips are supported by grating at the tank's bottom. The removal tank also contains a mixture of water and nutrient solution (N, P, and K with micronutrients), which is recirculated and sprayed over the media. Artificial addition of substrate to the system is typically not required because the bacteria enter the process tank with the biogas. Air is also added to the biogas to provide the required oxygen for the bacteria. Since biogas/air mixtures with over 10 percent oxygen are combustible or explosive, less than 10 percent air is added to the biogas. For safety reasons, the oxygen (O_2) concentration and pH are continuously measured and transmitted to the computer control system. The tank is provided with drain and overflow nozzles (one each) to remove the surplus fluid.

The system for the pilot test will be sized to treat up to 100 scfm at 1,500 ppm H_2S with turn down to 50 scfm at 500 ppm H_2S content.

3.3.1.2 Package Siloxane Treatment System

There are two companies that manufacture packaged systems to clean biogas. Applied Filter Technology offers the SAGPack series. These are customized units designed and built to match specific biogas cleaning requirements. These systems can include any combination of compression, chilling, condensing/coalescing, siloxane removal, organic sulfur removal, desiccation, and particulate filters.

The other company is Pioneer Air Systems, Inc. The gas drying unit in the Pioneer system consists of cyclic refrigeration capable of achieving an outlet temperature of -20°F. The removal of siloxanes in the Pioneer system depends on liquid condensation (by adsorption with the condensed water) and polishing with activated carbon.

Both of these companies were contacted. The Applied Filter Technology was chosen as the technology to test for siloxane removal.

The package system for this pilot test program will be sized to treat 50 scfm of biogas, which is enough to run four of the existing 30-kW microturbines at RP-1.

Current technologies for H_2S removal require either chemical feed (i.e., iron salts) or media replacement (i.e., iron sponge), which typically result in high operating costs. Local experience in operating the biological H_2S removal system (level of difficulty and operational labor requirements) needs to be acquired and documented to analyze this system. This is also the case for the packaged siloxane removal system.

The proposed technologies (refrigerated dryer and biological H_2S removal) for this pilot test program have the potential of substantially reducing the gas treatment cost. However, the available data for these systems is not comprehensive to allow analysis of their efficiency or cost-effectiveness.

3.4 Outcomes of Task 2.2.3.b: Design Ultrasound Systems

The purpose of Task 2.2.3.b was to perform design activities for the process and sites selected in Tasks 2.2.1 and Task 2.2.2. Under Task 2.2.3.b, design activities were completed for ultrasound systems at City of Riverside WWTP.

Activities under Task 2.2.3.b included preparation of Ultrasound System Design and Construction Drawings. This design included equipment specifications and drawings to facilitate installation of the ultrasound optimization equipment in the host facility. The mechanical, electrical, instrumentation/controls, and site/civil drawings needed for field installation were prepared. Prepackaged pilot unit manufacturer's drawings and related information were provided and a site plan for installation was prepared. This task enabled the selected ultrasound systems to be integrated into the City of Riverside WWTP.

The drawings included in the ultrasound drawing package are listed in Table 3-9.

Table 3-9: Enhanced Anaerobic Digestion Ultrasound Demonstration Program at City of Riverside Drawing Package

Drawing No.	Drawing Title
T-1	Cover sheet and Drawing Index
G-1	Mechanical Legend
C-1	Site Layout
M-1	Overall Piping Plan
M-2	IWE.tec Piping Plan
M-3	Sonico Piping Plan and Sections
M-4	Piping Sections
E-1	Electrical Legend
E-2	Electrical Site Plan and Layout
E-3	Electrical One-Line Diagram
E-4	Electrical Schematics and Details
E-5	Electrical LCP Elevations
E-6	Electrical Control Diagrams
E-7	Electrical Control Diagrams

I-1	Instrumentation Legends and Symbols
I-2	Ultrasound Pilot System P&ID
P-1	Site Photos

Below are descriptions of each of the technologies that were incorporated into the design.

3.4.1 IWE.tec Equipment Description

The IWE.tec approach to ultrasound application for municipal sludges is based on partial treatment of the secondary sludge stream. The premise is that, for this system, partial treatment is the most cost-effective approach. The ultrasound system consists of individual "cascade" probes, each within an individual cylindrical reactor. The "cascade" probe is a patented development of the common rod-shaped probe. The IWE.tec system operates at sonication times of 30 to 60 seconds. The systems are usually designed to run between 50 to 75 percent of the maximum power, to provide a buffer and prevent the units cutting out due to power overloads. Since this ultrasound system operates close to the maximum amplitude, the operating power draw can only be varied by changing the load, which may be achieved by changing line pressure, feed flow rate, or solids concentration of the feed sludge. Some of the recent advances that improve the cost-effectiveness of the IWE.tec system are as follows:

- Increase in the maximum amplitude from 25 μm to 50 μm.
- Increase in probe power, from 4 kW to potentially 16 kW. Probes over 4 kW have a new water cooling system.
- The probe design has been changed from single cast piece to a two-piece probe to allow the lower portion, which has the most wear, to be replaced more frequently, while the upper portion can be replaced less frequently.

Data from IWE.tec ultrasound systems in Germany show that the older design, using 2-kW probes at the lower amplitude range typically provided improvements in anaerobic digestion as follows:

- Increase in volatile solids destruction of 20 to 25 percent
- Increase in gas production of 25 to 30 percent
- Improved dewaterability of 0 to 5 percentage points

Actual results vary depending on digestion performance without ultrasound, digester retention times and the proportion of secondary solids in the digester feed.

3.4.1.1 Sonico Pilot Equipment Description

The Sonico ultrasound system consists of individual "radial" horns that are shaped like a ring donut. The horns are mounted in series in a reactor that typically contains three or five horns. The reactor is designed with flanges at either end that connect to a 6-inch-diameter pipe. The radial horn and reactor designs are covered by patents.

The Sonico approach to ultrasound application for municipal sludges is based on treatment of the entire secondary sludge stream. The Sonico system operates at sonication times of around 2 seconds. Recent tests conducted by Sonico show that maintaining the desired power draw is key to achieving the optimal ultrasound dose and intensity. The system does this by adjusting amplitude and line pressure to maintain the set power draw. This prevents the units cutting out on overload, and prevents performance dropping when changes in the sludge feed system would otherwise have reduced the power draw. The system is designed to typically run at 70 to 75 percent of the maximum amplitude, which provides buffering for changing loads. Some of the recent advances made by Sonico to improve the cost-effectiveness of the system are:

- Increase in the maximum amplitude from 12 μm to 16 μm.
- Increase in power, from 3 kW to 6 kW horns.
- More cost-effective horn manufacturing process.
- Improvements in the transducer cooling system.

Data from Sonico ultrasound systems show that the older design, using 3-kW probes at the lower amplitude range typically provided improvements in anaerobic digestion as follows:

- Increase in volatile solids destruction of 30 to 50 percent
- Increase in gas production of 30 to 50 percent
- Improved dewaterability of 0 to 2.5 percent

Actual results vary depending on digestion performance without ultrasound, digester retention times and the proportion of secondary solids in the digester feed.

3.4.1.2 Scope of Supply

The manufacturers shall provide the ultrasound demonstration equipment as an integrated operating system and shall consist of an equipment skid or container, necessary horns, transducers, generators to treat the specified TWAS flow; cooling system; flow meter(s); two pressure sensors; interconnecting pipes, bypass line, valves, instrumentation, control panels; sample stations; and interconnecting power/control wiring and associated raceways.

The manufacturers shall be responsible for designing their ultrasound demonstration system; delivering to the plant; providing installation instruction and assistance, training of the City of Riverside staff, commissioning, acceptance testing, and decommissioning.

The manufacturers shall be responsible for acceptance testing of individual items of equipment prior to demonstration testing. The City of Riverside shall install the equipment per the manufacturer's requirements and will provide manpower during startup.

3.4.1.3 Required Ancillary Equipment

The required ancillary system will include a 10,000-gallon TWAS holding tank with low, high, and high-high level controls to allow continuous flow through the ultrasound equipment systems; temporary piping between the TWAS feed line, the ultrasound demonstration systems and the digesters; TWAS progressive cavity feed pump for IWE.tec Ultrasound train; emergency bypass line and automatic valving to prevent overflow of the TWAS holding tank by diverting the TWAS feed flow to digesters 1 and 2; plug valves to isolate demonstration equipment from the sewage treatment plant; temporary power and control cable to connect to the plant system; and digester gas flow meters. Additional services and utilities that will be required include power supply; plant effluent for cooling; daily staffing and monitoring; and sampling and laboratory analysis during the testing period.

3.5 Outcomes of Task 2.2.4.a: Install Gas Cleaning Systems

The purpose of Task 2.2.4.a was to perform construction activities for the designs completed in Tasks 2.2.3.a. Under Task 2.2.4.a, construction activities were completed for gas cleaning systems at IEUA Regional Plant No. 1.

The gas drying system for moisture removal was installed downstream of the existing gas compressors and was physically located east of the existing gas compressors and iron sponges. The biological H_2S removal system was installed north of Digester 4 and this technology was compared to the existing chemical H_2S removal system using ferric chloride. The packaged siloxane treatment system was located south-east of the digesters, close to the energy recovery building. The pilot test equipment was installed outdoors and temporary piping was used to feed each of the systems.

Under this task, installation of the microturbine gas cleaning systems was completed in accordance with the design. This was accomplished with staff from the host facility (IEUA) as well as vendor and Commerce Energy Team personnel. Installation activities were accomplished in accordance with all local codes and standard practices. Startup and testing of the gas cleaning systems were also undertaken in this task. The final activities completed on this task were the submission of a letter to the Energy Commission stating that the installation was completed and submission of as-built drawings for the installed microturbine and gas cleaning system to the Energy Commission and the host facility.

Figure 3-12 shows the installed biological scrubber gas cleaning system.

Figure 3-12: Installed Biological Scrubber Gas Cleaning System

Figure 3-13 shows the installed chiller, which is the moisture removal portion of the gas cleaning system and also removes siloxane.

Figure 3-13: Installed Chiller (Moisture Removal System)

Figure 3-14 shows the siloxane removal system portion of the gas cleaning system.

Figure 3-14: Installed Siloxane Removal System

3.6 Outcomes of Task 2.2.4.b: Install Ultrasound Systems

The purpose of Task 2.2.4.b was to perform construction activities for the designs completed in Tasks 2.2.3.b. Under Task 2.2.4.b, construction activities were completed for ultrasound systems at City of Riverside WWTP.

Two ultrasound supplier systems were installed for the side-by-side comparison of the technology. The test equipment was installed on the TWAS feed (which is harder to break down in the conventional digestion process) to the digesters. To provide a consistent feed to the ultrasound systems, a TWAS holding tank was installed to provide buffering of the TWAS flow from the DAFTs, which is not continuous throughout the day as the pumps cycle on and off depending on levels in the DAFT tanks. The holding tank and demonstration equipment are located outside, on the south side of the test digesters. Temporary piping feeds the system. The TWAS from each ultrasound system mixes with the primary sludge in the digester. A master control panel was provided to integrate operation of the ultrasound systems with the TWAS holding tank level. The Sonico ultrasound demonstration system feeds Digester 1; the IWE.tec system feeds Digester 2. As the IWE.tec system only treats part (30 percent) of the TWAS flow, this unit has a bypass line through which the unsonicated portion is routed to Digester 2.

Under this task installation activities for the ultrasound systems were completed in accordance with the design completed under Task 2.2.3.b. The Commerce Energy Team staff worked with staff from the vendors and host facilities to complete installation activities. Startup and testing activities were completed and a letter notifying the Energy Commission that the system was completed and As-Built Drawings for the installed ultrasound systems were prepared and provided to the Energy Commission and the City of Riverside.

Figure 3-15 shows the installed ultrasound systems at the City of Riverside WWTP.

Figure 3-15: Installed Ultrasound Systems

3.7 Outcomes of Task 2.2.5: Collect and Analyze Data

The purpose of Task 2.2.5 was to collect and analyze data for the microturbine gas cleaning systems and optimized anaerobic digestion system and then report those findings in a series of quarterly reports. A total of six quarterly data reports were prepared during the course of the project. Contents of these reports are summarized below:

- First Quarterly Data Report: Summarized the baseline test results obtained from June 1, 2004, to August 31, 2004, for the enhanced anaerobic digestion using ultrasound.
- Second Quarterly Data Report: Presented the test results of the ultrasound test phase from September 1, 2004, to November 30, 2004. This report also included baseline data for the microturbine gas cleaning test at RP-1.
- Third Quarterly Data Report: presented the test results of the ultrasound test phase from December 1, 2004, through February 28, 2005. This report also included baseline data for the microturbine gas cleaning test at RP-1.
- Fourth Quarterly Data Report: presented the test results of the continuation phase of the ultrasound testing project that covered the period from March 1, 2005, to May 31, 2005. The continuation phase was conducted to continue monitoring digester performance after the shutdown of the ultrasound equipment. Additional baseline siloxane data, obtained during the same time period of March 2005 to May 2005, are included in this report.
- Fifth Quarterly Data Report: presented the test results of the gas cleaning test phase from June 1, 2005 through August 31, 2005.

- Sixth Quarterly Data Report: presented the test results of the gas cleaning continuation phase from September 1, 2005 through November 30, 2005.

Detailed results for each of these reporting periods are included in the Quarterly report. Results obtained from the pilot tests are summarized below.

3.7.1 Enhanced Anaerobic Digestion

During the baseline and ultrasound test periods, the digesters were monitored for a number of key performance parameters, such as gas production and volatile solids reduction (VSR). The two test digesters, digesters 1 and 2, were the main focus. Digester 3, which is a smaller digester, was operated slightly differently. However, monitoring of this digester was used to verify trends seen in the other two digesters.

Tables 3-10 and 3-11 summarize these results.

Similar digester feed sludge characteristics and digester operating conditions were maintained until April 27, 2005 (continuation phase), at which time another project conducted by Riverside was started, to pilot test addition of fat oil and grease (FOG) from restaurants. Initially, 10,000 gallons per week of FOG were added to Digester 2. This volume was increased to 40,000 gallons per week by mid-May 2005. Excluding the data from November 2004 when Digester 1 was overfed and the HRT dropped, the average VSR for Digester 1 was 55 percent for the ultrasound period, similar to the 57 percent obtained during the baseline period. During the continuation phase, Digester 1 achieved 59 percent VSR, marginally higher than the baseline and ultrasound phases. For Digester 2, the average VSR was 56 percent from September to mid-December 2004 with ultrasound equipment in place, similar to the baseline phase VSR of 54 percent. During the continuation phase Digester 2 achieved 59 percent VSR, slightly higher than the earlier phases. The VSR in the digester appeared to be increasing through May 2005, following the commencement of FOG addition to the digester. The average VSR in Digester 3 was 54, 56, and 59 percent during the baseline, ultrasound, and continuation phases, respectively. Given the accuracy of solids sampling and flow measurement through a digester, minor differences of VSR between digesters and the different testing phases are within the margin of error.

Table 3-10: Summary of Digester Operation and Cost During Each Test Phase

Digester Data	Units	Digester 1				Digester 2				Digester 3			
		Baseline Phase (6/1/04 - 8/31/04)	Test Phase (With Sonico Ultrasound System)		Continuation Phase (No Ultrasound) 3/1/05 – 5/31/05	Baseline Phase (6/1/04 - 8/31/04)	Test Phase (With IWE.tec/Hielscher Ultrasound System[1])		Continuation Phase (No Ultrasound) 3/1/05 – 5/31/05	Baseline Phase (6/1/04 - 8/31/04)	Test Phase (no ultrasound system installation)		Continuation Phase (No Ultrasound) 3/1/05 – 5/31/05
			(9/1/04 - 11/30/04)[3]	(12/1/04 - 2/28/05)			(9/1/04 - 11/30/04)[3]	(12/1/04 - 2/28/05)			(9/1/04 - 11/30/04)	(12/1/04 - 2/28/05)	
Operational Parameters													
Volatile Solids Reduction (VSR)	%	57	52	58	59	54	54	58	59	54	54	57	59
Biogas Production[2]	cfd	181,460	175,430	171,650	180,960	153,910	144,950	174,880	196,590	117,380[4]	112,130[4]	121,280[4]	127,231
Biogas Production Yield	cfd/lb VSR	15.6	15	13.3	14.7	13.9	13.6	14.4	14.9	17	15	14.8	15.2
Cost As Tested													
Installation Cost	$	NA	$231,500		NA	NA	$205,500		NA	NA	NA	NA	NA
Additional Electricity Cost	$	NA	$2,834	$1,244	NA	NA	$1,344	$432	NA	NA	NA	NA	NA
Ultrasound Maintenance Cost	$	NA	$14,000	$14,000	NA	NA	$40,000	$40,000	NA	NA	NA	NA	NA
Polymer Cost	$	$23,871	$23,871	$17,938	$23,871	$23,871	$23,871	$23,871	$23,871	$23,871	NA	NA	$23,871
Biosolids Management Cost	$	$146,264	$146,264	$109,261	$146,264	$146,264	$146,264	$146,264	$146,264	$146,264	NA	NA	$146,264
Labor Cost	$	NA	$3,640	$3,640	NA	NA	$5,460	$840	NA	NA	NA	NA	NA
Actual Total Operating Cost For Quarter	$	$170,135	$190,609	$146,082	$170,135	$170,135	$216,939	$211,407	$170,135	$170,135	NA	NA	$170,135
Natural Gas Offset Value	$	($92,096)	($92,096)	($94,490)	($92,096)	($92,096)	($92,096)	($92,096)	($92,096)	($92,096)	NA	NA	($92,096)
Actual Net O&M	$	$78,039	$98,513	$51,592	$78,039	$78,039	$124,843	$119,311	$78,039	$78,039	NA	NA	$78,039
Average Annual Net O&M	$	$312,157	$300,211		$312,157	$312,157	$488,309		$312,157	$312,157	NA	NA	$312,157
Reliability													
Percentage of Days Operated	%	NA	90%	41%	NA	NA	31%	NA[5]	NA	NA	NA	NA	NA

NA = Not applicable.

1 IWE.tec Ultrasound System was decommissioned in December 2004 as a result of problems encountered with the ultrasound equipment provided by Hielscher.

2 Numbers were rounded to the nearest 10.

3 Averages included November 2004 data and thus were impacted by the unequal TWAS flow to digesters 1 and 2.

4 Biogas flow from Digester 3 was not available. A new gas meter was installed in July 2004, but it was not calibrated or connected to the SCADA system. Gas is calculated from the difference between the total gas flow meter and digesters 1 and 2 and includes a small amount of gas from Digester 4.

5 IWE.tec equipment only ran 9 days in the third quarter and was decommissioned in mid-December.

Table 3-11: Summary of the Ultrasounds Affects on Dewaterability

Parameter	Units	Baseline Phase (6/1/04 – 8/31/04)	Ultrasound Phase (9/1/04 – 11/30/04)	Ultrasound Phase (12/1/04 – 2/28/05)	Continuation Phase (3/1/05 – 5/31/05)
BFP Dewatered Cake					
Quantity	wtpd	165	133	39	48
TS%	%	13%	14%	17%	14.70%
BFP Operation					
Polymer	lb/ton	26	27	20	27

Digester 1 had consistently produced more biogas than Digester 2 starting from the baseline period through the first-3-month of the ultrasound test period after which biogas production was similar for the two digesters. During the baseline period, the average gas production was 181,460 cf/d for Digester 1 and 153,910 cf/d for Digester 2. During the first 3-month ultrasound period, the gas production from both digesters was slightly lower than during the baseline period: the average for Digester 1 was 175,430 cf/d and for Digester 2 was 144,950 cf/d. The difference in gas production could largely be attributed to the higher TWAS flow to Digester 1 and a lower flow to Digester 2 as a result of problems with the TWAS feed pump to Digester 2. During the second 3-month ultrasound test period, the average gas production from digesters 1 and 2 was 171,650 cfd and 174,880 cfd, respectively. During this period, the Digester 2 ultrasound system had been turned off and the flows to the two digesters were more balanced. During the continuation phase, gas production from digesters 1 and 2 was similar, averaging 180,960 cf/d and 196,590 cf/d, respectively, until addition of grease loads. Average gas production for Digester 2 during May 2005 was 219,000 cf/d, owing to FOG addition. Digester 3, which is a smaller digester, had less biogas produced because it had less volatile solids fed to it.

The gas meters on digesters 1 and 2 were interchanged on August 4, 2005, to ascertain whether there was a difference in the meters, but no change in gas production was seen. Based on the piping configuration, reverse flow of the gas is possible when the co-generation system is not operating. However, during the baseline and ultrasound phase from September 2004 to February 2005, the co-generation facility was operating normally. Examination of the total metered gas sent to the plant’s co-generation system shows a slight increase of 4 percent in gas production between the baseline and ultrasound phase (from an average 452,400 cfd to 472,680 cfd). This slight variation might be due to an increase in the solids load to the digesters, which showed a 4.5 percent increase. This indicates that the installation of the two ultrasound systems did not significantly increase the total gas production from the overall digestion system.

A similar trend to gas production was observed for the biogas yield, or the amount of gas generated per unit mass of solids destroyed. Digester 1 showed higher biogas yield than Digester 2 from the baseline period to the end to November 2004, after which biogas yields were similar for the two digesters. For the second half of the 6-month ultrasound test period, the average biogas yield was 13.3 and 14.4 cf/lb VSR for digesters 1 and 2, respectively. Overall, for Digester 1, the calculated biogas yield averaged 15.6, 14.1, and 14.7 cf/lb VSR for baseline, ultrasound, and continuation periods, respectively. For Digester 2, the calculated biogas yield averaged 13.9, 14.0, and 14.9 cf/lb VSR for baseline, ultrasound, and continuation periods, respectively. The biogas yield from Digester 3 was 17, 14.9, and 14.8 cf/lb VSR during the baseline and ultrasound period, respectively. The biogas production from this digester was not directly measured, so the calculated biogas yield can only be used as a reference. A biogas yield of 16 cf/lb VSR is normally taken as the theoretical value.

Chemical data for alkalinity, pH, volatile acids, ammonia, and total Kjeldahl nitrogen (TKN) in digesters 1, 2, and 3 were similar.

The Sonico system was more reliable than the IWE.tec system and the use of multiple lower-power stacks provided better redundancy, allowing for 65 percent uptime over the 6-month ultrasound testing period. For the IWE.tec system, there were two main sources of problems with operation of the unit. The first was with the ultrasound stacks themselves. For much of the time, the power draw was below the target range, and the transducers repeatedly failed, being unable to maintain frequency. In addition, the oil and water cooling system did not appear to be appropriate for this application. The periods of nonoperation were also increased as replacement parts and a Hielscher technician had to be sent from Germany, and there were often delays with the equipment at U.S. customs. By the end of this test period, it was clear that the high-power ultrasound units were not suitable for application on TWAS, nor was the cooling system suitable for the high loads on the transducers and the high temperatures in southern California.

Installation, operation, and maintenance costs are summarized in Table 3-10. As shown in the table, the Sonico system was slightly more expensive to install than the IWE.tec system. However, Sonico was much less expensive to operate.

The dewaterability of digested solids is a key cost component for digester operation and the cost-benefit analysis of using ultrasound. With the use of ultrasound, there is the potential to improve dewaterability through less use of polymer and production of a drier cake.

Data from the second half of the ultrasound period showed that the two belt filter presses (BFPs) achieved a cake solids concentration of approximately 17 percent, significantly higher compared with 14 percent and 13 percent for the first half of the ultrasound testing period and baseline phase. This value is within the range of what would be expected from BFP dewatering of digested sludge, where solids concentrations of 14 to 18 percent are more typical. During the continuation phase the performance dropped to an average of 14.7 percent. Polymer use during the second half ultrasound period averaged 20 lb/ton of solids processed, which is significantly lower than 26 and 27 lb/ton during the other phases. Considering the balance of BFP flow rates and polymer dose against TS concentration, it appears that dewaterability was better between October 2004 and March 2005, compared with the baseline period and the end of the continuation period. It is possible that some of this improvement may have been due to installation of the ultrasound system. Due to the HRT in the digester, a time lag would be expected between installation of the ultrasound system and changes in dewaterability. Seasonal variations may also have impacted dewaterability.

The dewatering centrifuge was not in full operation until February 2005. Therefore, data from the centrifuge is not particularly applicable.

3.7.2 Microturbine Gas Cleaning

Three gas cleaning systems were installed and tested at IEUA's Regional Plant No. 1 during this project. The first system included a chiller that had two purposes: moisture removal and siloxane removal. The second system tested was a biological scrubber system that was installed to remove H_2S from the gas stream. The third system tested involved using different absorption media for siloxane removal, a graphite-based media and a polymer-based media. In addition to these systems, a fourth system was installed to test enhanced iron sponge through air injection. However, this fourth system is not discussed in this report (see the Final 3.1 Report for details).

During the baseline and gas cleaning test periods, the digesters and gas treatment systems were monitored for a number of key operational and performance parameters, such as ferric chloride addition, volatile solids (VS) fed to the digesters, VS reduction, digester gas production, H_2S concentration in the digester gas, and H_2S in the combined gas before and after the iron sponge system. These results are discussed in the quarterly reports.

Table 3-11 summarizes the gas cleaning system operation results.

3.7.2.1 Gas Drying

The chiller was operated and tested between July 2005 and December 2005. Figures 3-16 through 3-18 and Table 3-12 summarize the chiller's performance in removing moisture.

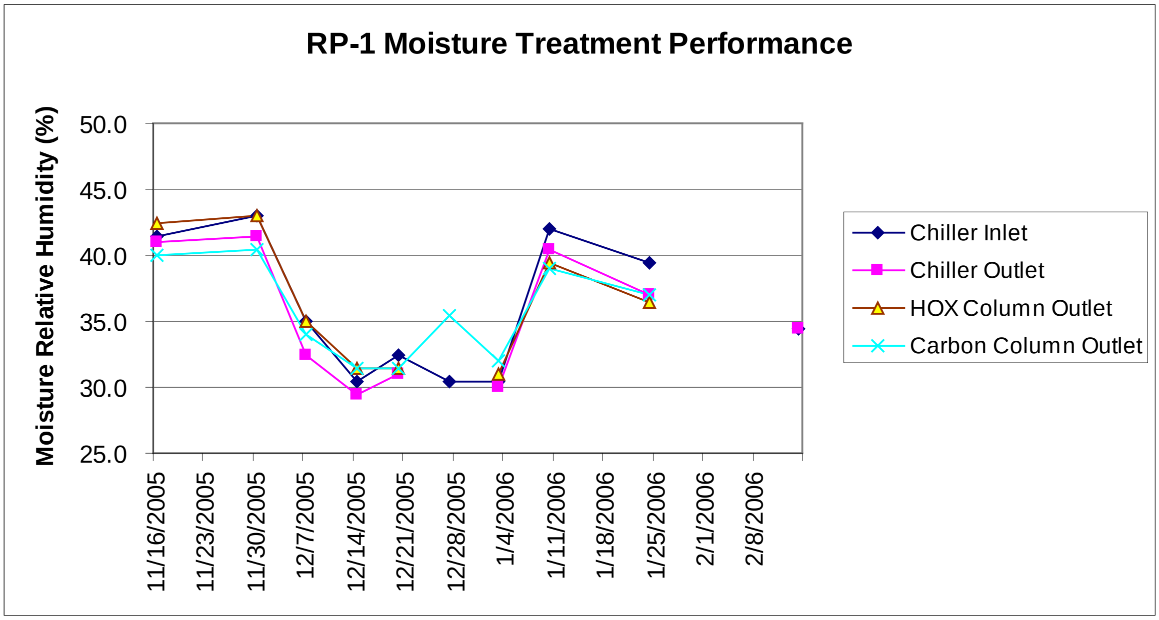


Figure 3-16: Moisture Treatment Performance: Relative Humidity

Table 3-12: Summary of Gas System Operation and Performance

	Units	Baseline (July/04 - May/05)	Baseline 12-Oct-04	Baseline 16-Nov-04	With Project SagPak HOX-Based (Oct/05 - Dec/05)		With Project SagPak C-Based (Oct/05 - Dec/05)		With Project Chiller (Oct/05 - Dec/05)		With Project H_2S Scrubber (Oct/05 - Dec/05)		With Project Iron Sponge (July/05 - Dec/05)
					Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	
Operational Parameters													
Biogas Production Total	cfd	707,000	230,000	640,000									
Biogas Production Digester 4	cfd	107,000	97,000	116,000									
H_2S[1]	ppmv	-	77	26	-	-	-	-	-	-	1,263	14	19[5]
Moisture	mg/mL	-	0.016		0.008	0.008	0.008	0.008	0.009	0.008	-	-	-
Siloxane	ppbv	518	36,000[2]	5,000[3]	-	-	-	-	2,885	1,223	-	-	-
Siloxane	ppbv	518	36,000[2]	5,000[3]	2,470	613	1,470	181	3,660	2,470	-	-	-
Cost As Tested													
Installation Cost	$	-	-	-	53,815[4]		53,815[4]		151,570		417,860		157,500[6]
Annual Operating Cost	$	-	-	-	8,750		8,750		8,750		8,750		8,750
Reliability													
Percentage of Days Operated	%	NA	NA	NA	47%		47%		47%		100%		

NA = Not applicable.

[1] Digester 4 data; with $FeCl_3$ addition for H_2S control during baseline, and without $FeCl_3$ addition after project implementation.

[2] Combined gas at the flare.

[3] Combined gas after the compressors.

[4] Price of media replacement.

[5] No change from baseline gas loop measurements. Field test period was insufficient to determine useful life of test unit.

[6] Price of modifications to existing system and media addition.

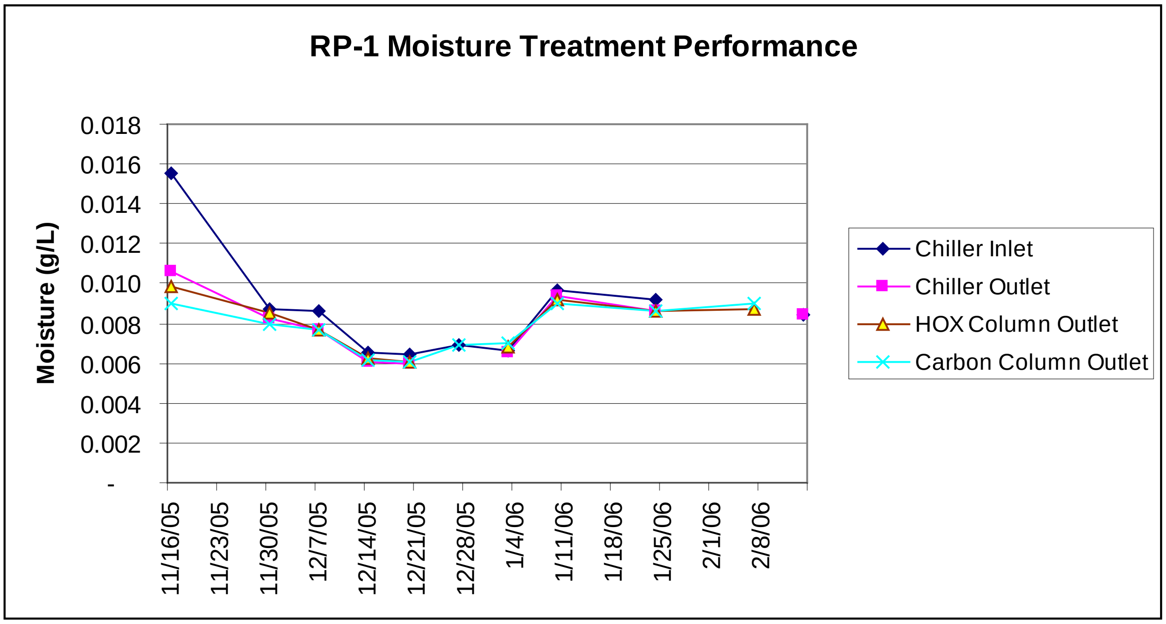


Figure 3-17: Moisture Treatment Performance: Moisture

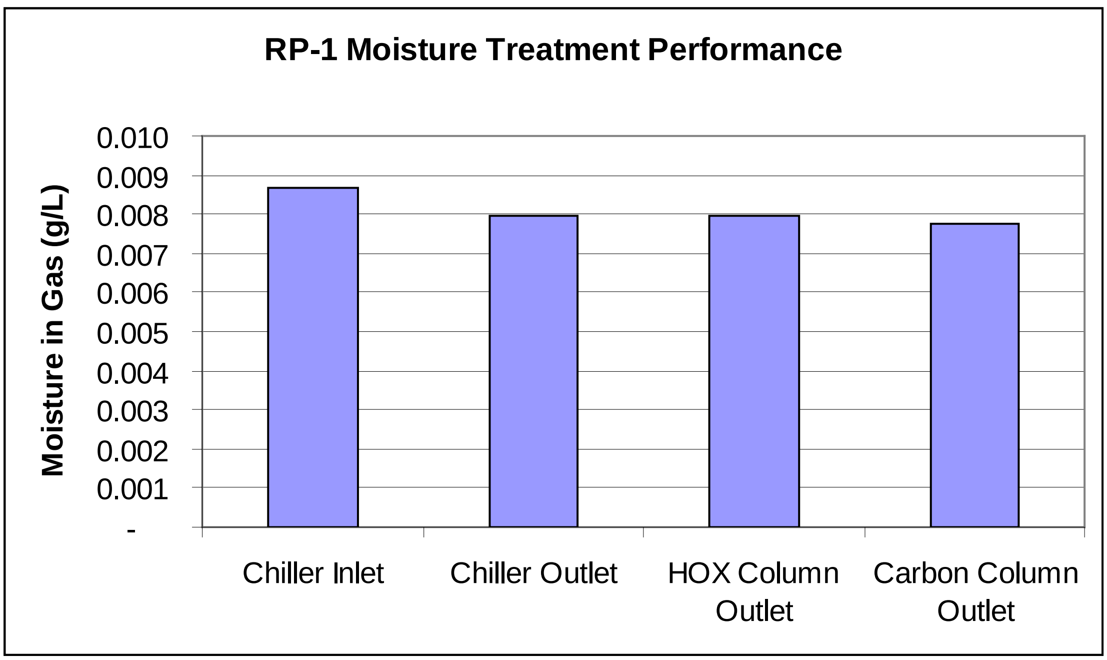


Figure 3-18: Moisture Treatment Performance: Moisture in Gas

The chiller performed relatively well during the test period, however the unit only functioned 47 percent of the operating time.

This unit was cost-effective because it served two functions: moisture removal and siloxane removal, as shown in the above figures and in Table 3-12.

3.7.2.1 H_2S Removal

The H_2S scrubber installed and tested under this project was a biological treatment unit. This unit was operated and tested between July 2005 and December 2005. Figure 3-19 and Table 3-12 summarize the scrubber's performance in removing H_2S.

As shown in Figure 3-19, this unit was very effective. With the shutdown of H_2S control with $FeCl_3$ addition, the H_2S level increased beyond the detection level of the H_2S meter, yet the H_2S level at the scrubber outlet was below 15 ppm.

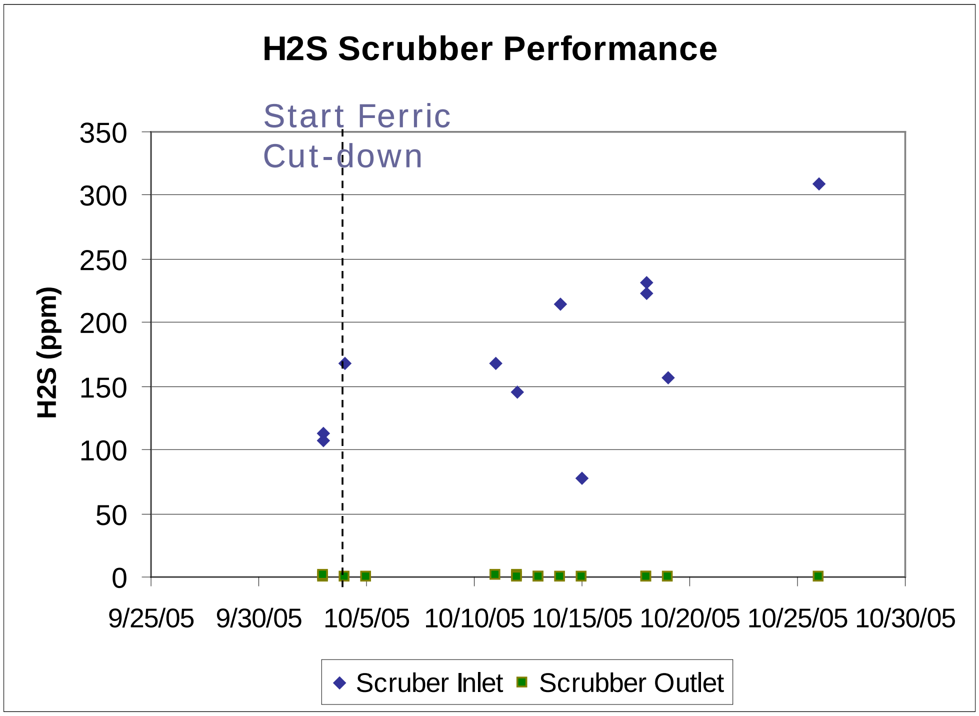


Figure 3-19: H_2S Scrubber Performance

Because this unit is based on biological treatment, this technology reduces or eliminates chemical usage (e.g., ferric chloride addition for H_2S control) at the facility. Another advantage of the unit was the easy and automated operation, and minimal operator attention and labor requirements. This system was the most reliable of the three systems tested and operated 100 percent of the operating time. Out of all the systems tested, the biological scrubber offered the most significant advantages from operational and economic standpoints.

3.7.2.2 Siloxane Treatment

The package siloxane treatment system (SagPack columns) installed and tested under this project was operated and tested between July 2005 and December 2005. Two siloxane removal media were tested during this project. The SagPack columns were packed with either graphite-based or polymer-based media treatment. Figures 3-20 and 3-21 and Table 3-12 summarize the scrubber's performance in removing H_2S.

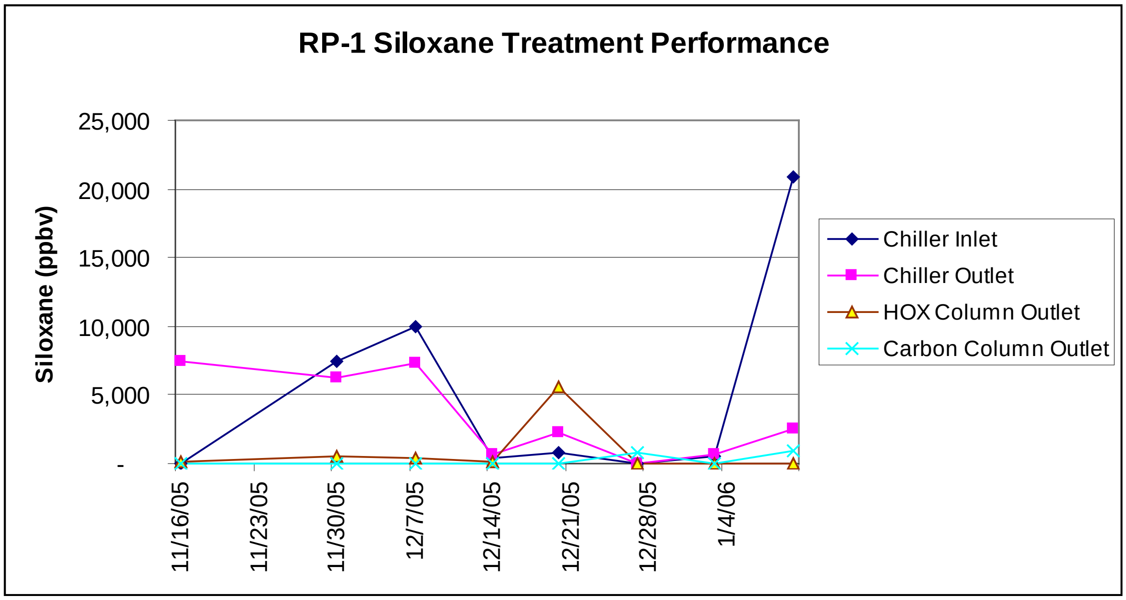


Figure 3-20: Siloxane Treatment Performance: Siloxane

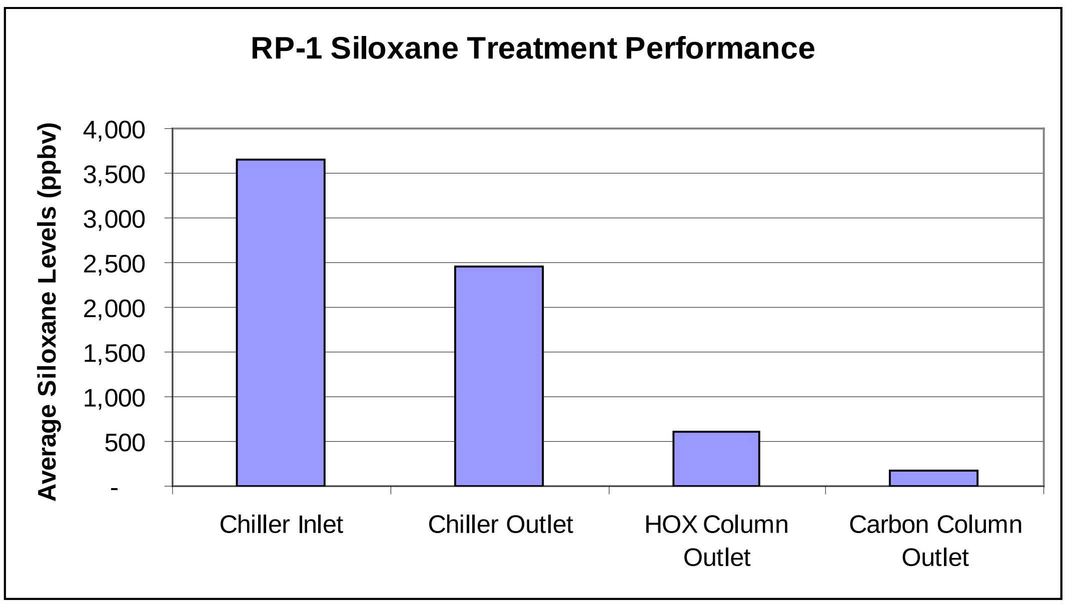


Figure 3-21: Siloxane Treatment Performance: Average Siloxane Levels

As shown in the above figures and Table 3-12, the siloxane treatment system was effective at removing siloxane. However, media capacity was not completely determined within the project test period. Media capacity and useful life of these media need to be determined for a thorough technology analysis. This equipment was not as reliable as the H_2S scrubber. However, it operated at the same percentage of time, 47 percent, as the moisture removal equipment.

CHAPTER 4: Conclusions and Recommendations

The overall goal of Project 2.2 is to increase biogas power generation at wastewater treatment plants. The project has two elements: ultrasound and gas cleaning. The ultrasound element grew out of tasks that examined ultrasound, thermal hydrolysis, and other technologies that enhanced the anaerobic digestion process leading to higher levels of biogas production. Under this element, two ultrasound technologies were tested to determine their effectiveness in breaking down cell walls in sewage sludge prior to entering an anaerobic digester. The intent of using ultrasound is to increase solids destruction and increase biogas production, thus increasing the amount of biogas available for power generation and reducing the amount of residual material requiring offsite disposal.

The second element of this project involves the installation and testing of biogas cleaning systems to determine their cost-effectiveness in making renewable energy more affordable. In general, more effective gas cleaning systems are increasingly being used in biogas power generation systems. The gas cleaning systems are needed to allow the microturbines, engine-generators, and other systems to operate for longer periods of time between maintenance activities and to improve performance, including lowering emissions. The goals of the project are shown below.

4.1 Goals of Project 2.2

The objectives of Enhanced Energy Recovery through Optimization of Anaerobic Digestion and Microturbines project are to:

- Increase and optimize digester gas production through thermal hydrolysis and ultrasound processes
- Develop and optimize cost-effective gas cleanup systems
- Evaluate and quantify environmental benefits that result from using microturbines at sewage treatment plants
- Evaluate performance and cost during operation so sewage treatment plants have greater certainty on cost and reliability of using microturbines

4.2 Key Findings of Project 2.2

There were four key findings reached as a result of the effort on this project. The relationship of each finding to the relevant project goal, the related activities undertaken on the Project, results, conclusions and applicability to other projects is discussed below.

1. **Ultrasound offers potential for increased gas production in "stressed systems," but does not lead to increased solids destruction or significant increase in biogas production in systems with adequate holding times**. Testing showed that in systems

with adequate holding times, ultrasound did not significantly increase biogas production or solids destruction over what would be expected without ultrasound.

Relevant Project Goal: Increase and optimize digester gas production through thermal hydrolysis and ultrasound processes

Description of Activities Conducted during the Project: Two systems, one manufactured by IWE.tec and the other by Sonico were tested side-by-side at the City of Riverside WWTP. The testing program included a pretest baseline phase, a testing phase and a post testing phase.

Results of Project Activities: The IWE.tec system, which employs newer technology that utilizes larger sonic horns, did not operate reliably during the testing period. The Sonico system had some operational challenges, but operated more reliably than the IWE.tec system. Results of the testing suggested that the ultrasound systems were effective in increasing solids reduction when the systems were stressed (holding times of 15 days or less). Later in the test when the holding time was longer, biogas production and solids destruction were not significantly higher for the ultrasound treated sludge than for the control system. Table 4-1 presents the results for the different testing periods.

Conclusions: Ultrasound technology can have beneficial effects on systems where there is not adequate time for digestion. At the City of Riverside, once operational changes were made and all systems had adequate holding time, treatment of the sludge by either system did not significantly increase gas production or solids destruction.

Application of Findings to California: The findings confirmed that ultrasound technology can improve digester performance in some instances, but is not justified under normal operating conditions.

2. **If ultrasound is to be employed, sonic horns, in the size range of 6 kW or less, are more reliable than the larger-sized horns vendors have manufactured recently**. Vendors appear to have taken the findings of the Commerce Energy PIER Program into account and have scaled back their offering of larger sized sonic horns in the wastewater treatment market.

   Relevant Project Goal: Increase and optimize digester gas production through thermal hydrolysis and ultrasound processes

   Description of Activities Conducted during the Project: Two systems, one manufactured by IWE.tec, and the other by Sonico were tested side-by-side at the City of Riverside WWTP (see Figures 4-1 and 4-2). The testing program included a pretest baseline phase, a testing phase and a post testing phase.

Table 4-1: Technical, Environmental, and Economic Performance of Ultrasound Units

As tested at full scale at Riverside WWTP

Engineering/Economic Consideration	Baseline—each digester, as tested, no ultrasound	Ultrasound—Sonico Unit (as tested)	Ultrasound—IWE.tec Unit (as tested)	Baseline—full-scale (all Riverside WWT digesters)	With Ultrasound—selected unit (Sonico) at full scale
Operational Parameters					
Volatile Solids Reduction (VSR), %	54 - 57%	52 - 58%	54 - 58%	54 - 57%	52 - 58%
Biogas Production Yield (cfd/lbVSR)	14 - 17	13 - 15	13 - 15	14 - 16	13 - 16
Increase in biogas production	N/A	0	0	N/A	0
Reliability of Unit	N/A	66%	21%	N/A	75 - 85%
Dewaterability					
TS% of dewatered cake from belt filter press	13%	14 - 17%	13%	13%	14 - 17%
Polymer use at belt filter press (lb/ton)	26	20 - 27	26	26	20 - 27
Environmental Benefits					
Greenhouse Gas (GHG) Reductions	N/A	0	0	0	0
Anticipated to be 0, since no measurable increase in gas production was observed, so no additional methane capture					
Renewable Energy Credits (RECs)	N/A	0	0	0	0
Anticipated to be 0, since no measurable increase in gas production was observed, so no additional energy generation					
Capital Costs					
Total installed cost of ultrasound equipment	N/A	$231,500	$205,500	N/A	$1,876,000
TOTAL INVESTMENT	**N/A**	**$231,500**	**$205,500**	**N/A**	**$1,876,000**
O&M Costs (Annual)					
Biosolids Management Cost	$585,055	$511,048	$585,055	$1,579,647	$1,287,711
Polymer Cost	$95,485	$83,617	$95,485	$257,808	$210,694
Ultrasound Additional Electricity Cost	$0	$8,156	$3,552	$0	$34,690
Ultrasound Maintenance Cost	$0	$56,000	$160,000	$0	$126,000
Ultrasound Labor Cost	$0	$14,560	$12,600	$0	$14,560
TOTAL ANNUAL O&M	**$680,539**	**$673,382**	**$856,691**	**$1,837,455**	**$1,673,655**
TOTAL O&M SAVINGS	**N/A**	**$7,157**	**($176,152)**	**N/A**	**$163,801**
Life Cycle Analysis					
Present Value of O&M savings at 6% discount rate, 15-year project life	N/A	$69,512	($1,710,832)	N/A	$1,590,872
Net Present Value of Investment	N/A	($161,988)	($1,916,332)	N/A	($285,128)
Simple Payback period (years)	N/A	32.3	N/A	N/A	11.5
Rate of return (percent)	N/A	-8%	N/A	N/A	4%

Table 4-1: Technical, Environmental, and Economic Performance of Ultrasound Units

As tested at full scale at Riverside WWTP

Engineering/Economic Consideration	Baseline—each digester, as tested, no ultrasound	Ultrasound—Sonico Unit (as tested)	Ultrasound—IWE.tec Unit (as tested)	Baseline—full-scale (all Riverside WWT digesters)	With Ultrasound—selected unit (Sonico) at full scale

*Some values are rounded.

Figure 4-1: Sonico System Installed at the City of Riverside

Figure 4-2: IWE.tec System Installed at the City of Riverside

Compliments of Sonico Compliments of IWE.tec

Results of Project Activities: The IWE.tec system, which employs newer technology, and larger sonic horns did not operate reliably during the testing period. The Sonico system had some operational challenges, but operated more reliably than the IWE.tec system. Larger horns were less reliable, consumed more power and did not provide significant benefits. Results of the testing suggested that the ultrasound systems were effective in increasing solids reduction when the systems were stressed (holding times of 15 days or less). Later in the test when the holding time was longer, biogas production and solids destruction were not significantly higher for the ultrasound treated sludge than for the control system. Table 4-1 presents the results for the different testing periods.

Conclusions: Newer, larger (6 kW and larger sonic horns) are not recommended for installations where holding times are not limited. Further, since the testing under this program was completed, ultrasound technology vendors have changed their marketing plans and are focusing on the smaller size sonic horns.

Application of Findings to California: There are a relatively small number of wastewater treatment plants in California where the systems are stressed and consequently where ultrasound technology could be cost-effective. In general it is a technology where specialized, rather than general applications are warranted, and pay back time can be long if the conditions are not right.

Table 4-1 documents the technical, environmental, and economic performance of ultrasound units, as tested at full-scale implementation at Riverside WWTP.

3. **Improved gas cleaning technologies are very important to the economics of biogas projects.** The gas cleaning technologies tested enable lower emitting technologies such as microturbines to be deployed and also improve the overall life cycle cost for other generation systems such as reciprocating engines. Improved gas cleaning technology is one of the most important factors in expanding biogas generation levels. Improved technology allows existing projects to operate more reliably and more projects to become economic with the installation of improved gas cleaning systems.

   Relevant Project Goal: Develop and optimize cost-effective gas cleanup systems.

   Evaluate performance and cost during operation so sewage treatment plants have greater certainty on cost and reliability of cogeneration.

   Evaluate and quantify environmental benefits that result from using microturbines at sewage treatment plants.

   Description of Activities Conducted during the Project: Three gas cleaning systems were installed and tested at IEUA's Regional Plant No. 1. One system included a chiller that had two purposes: moisture removal and siloxane removal. A second system tested was a biological scrubber system that removes H_2S from the gas stream. The third system tested involved using different absorption media for siloxane removal, a graphite-based media and a polymer-based media. The final system tested was enhanced iron sponge through air injection.

   The H_2S scrubber installed and tested under this project (Figure 4-3) was a biological treatment unit. Because this unit is based on biological treatment, this technology reduces or eliminates chemical usage (e.g.; ferric chloride addition for H_2S control) at the facility. Another advantage of the unit was the easy and automated operation, and minimal operator attention and labor requirements.

   Siloxanes in digester gas have been increasing due to increased use of siloxane in consumer products which result in increased siloxanes reaching the wastewater treatment plants. In order to prevent cogeneration engine shutdowns, reduce engine maintenance requirements and biogas wasting during engine down periods, siloxane removal from digester gas needs to be practiced. This is especially important for this project, since the goals are to implement a system where improved digestion and increased biogas production are sought. The siloxane and moisture removal units are shown in Figure 4-4. Two siloxane removal media were tested during this project. The SagPack columns were packed with either a graphite-based or a polymer-based media for treatment. Media capacity and useful life of these media need to be determined for a thorough technology analysis.

Results of Project Activities: Three different gas treatment technologies were tested and evaluated in terms of their performance and life cycle costs. Of the systems tested, the biological scrubber offered the most significant advantages from operational and economic standpoints. Figure 3-19 illustrates the effectiveness of this unit that operated on Digester 4 (manure digester) gas. With the shutdown of the H_2S control with $FeCl_3$ addition, the H_2S concentration in the Digester 4 gas increased significantly. Later in the study the H_2S level increased beyond the detection level of the H_2S meter, yet the H_2S level at the scrubber outlet was below 15 ppm.

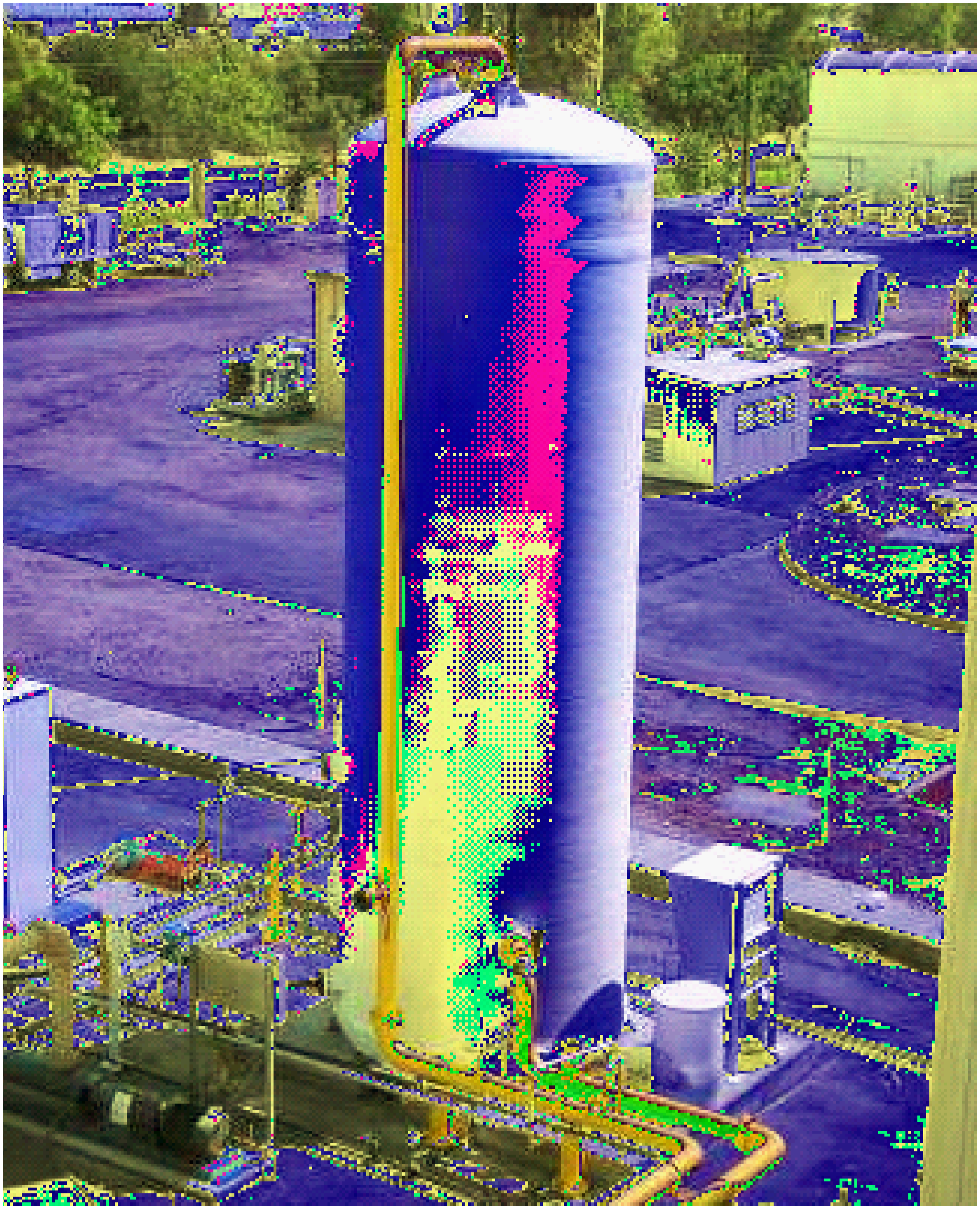


Figure 4-3: Biological H_2S Scrubber

Figure 4-4: Moisture and Siloxane Removal

The chiller also was cost-effective because it served two functions: moisture removal and siloxane removal. Table 4-2 summarizes the performance and cost-effectiveness of the moisture removal system.

Conclusions: All of the gas cleaning systems tested performed well. In general, the biological scrubber was the most cost-effective, reliable and low labor unit, and its use eliminated the need for chemical use thereby saving money and reducing environmental impacts. SagPak monitoring results showed siloxane removal. However, media capacity was not completely determined within the Project test period, and the unit useful life was not completely assessed. The other system functioned well, but as shown in Table 4-2 did not have the rate of return and was not as reliable.

Application of Findings to California: The results of the gas cleaning tests showed that biological H_2S scrubbers could be very efficient, easy to operate, non-labor intensive and cost-effective units for implementation at other facilities where H_2S removal from biogas is needed prior to cogeneration. Siloxane removal systems, though not as reliably, functioned to remove siloxane from the gas stream. With further assessment of media useful life, these units can be readily implemented at other California facilities.

4. **Biological scrubbers, as compared to iron sponges or other more standard control technologies, reduce the life cycle cost of H_2S removal systems**. By using biological media to capture the H_2S, chemical media purchases are reduced substantially. There is less solid waste generated and there is also a potential for recovering the sulfur.

Table 4-2: Summary of Gas System Operation and Performance

	Units	Baseline (July/04 - May/05)	Baseline 12-Oct-04	Baseline 16-Nov-04	With Project SagPak HOX-Based		With Project SagPak C-Based		With Project Chiller		With Project H_2S Scrubber		Baseline (July/05 - Dec/05)
					Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Baseline		
					(July/05 - Dec/05)		(July/05 - Dec/05)		(July/05 - Dec/05)		(July/05 - Dec/05)		
Operational Parameters													
Biogas Production Total	cfd	707,000	230,000	640,000									
Biogas Production Digester 4	cfd	107,000	97,000	116,000									
H_2S [1]	ppmv	-	77	26	-	-	-	-	-	H_2S [1]	ppmv	-	77
Moisture	mg/mL	-	0.016		0.008	0.008	0.008	0.008	0.009	Moisture	mg/ mL	-	0.016
Siloxane	ppbv	518	36,000[2]	5,000[3]	-	-	-	-	2,885	Siloxane	ppbv	518	36,000[2]
Siloxane	ppbv	518	36,000[2]	5,000[3]	2,470	613	1,470	181	3,660	Siloxane	ppbv	518	36,000[2]
Cost As Tested													
Installation Cost	$	-	-	-	53,815 [4]		53,815 [4]		151,570		417,860		157,500 [5]
Annual Operating Cost	$	-	-	-	8,750		8,750		8,750		8,750		8,750
Environmental Benefits													
SOX Reduction		-	-	-					6				
Annual Chemical/Media Use Reduction	$/year	-	-	-	-		-		53,815		79,200		NA
Reliability													
Percentage of Days Operated	%	NA	NA	NA	47%		47%		47%		100%		
Economic Analysis													
Total Annual Savings (= Environmental benefits less operating costs)	$/year								$45,065		$70,450		
Present value of annual savings; 6% discount rate, 10% project life	$								$331,682		$518,518		
Net Present Value (NPV) of investment	$								$180,112		$100,658		
Simple Payback	years								3.36		5.93		
Rate of Return (IRR)									27%		11%		

NA = Not applicable

1 Digester 4 data; with $FeCl_3$ addition for H_2S control during baseline, and without $FeCl_3$ addition after project implementation.

2 Combined gas at the flare.

3 Combined gas after the compressors.

4 Price of media replacement.

5 Price of modifications to existing system and media addition.

6 Assumes chiller saves one change-out per year of SagPak media.

Relevant Project Goals: Develop and optimize cost-effective gas cleanup systems.

Evaluate performance and cost during operation so sewage treatment plants have greater certainty on cost and reliability of using microturbines.

Evaluate and quantify environmental benefits that result from using microturbines at sewage treatment plants

Description of Activities Conducted during the Project: A biological scrubber was installed at IEUA Regional Plant No. 1. It was installed and tested to measure its performance. In addition, an economic analysis of its performance was completed.

Results of Project Activities: Figure 3-19 and Table 4-2 present the results of the testing of the biological scrubber. The unit performed exceptionally well in terms of reliability, ease of operation and removal capacity. Because the unit operation was automated to allow injection of air at pre-set levels and pH data to be recorded continuously, any changes in operation were detected quickly, and corrective actions were taken rapidly when needed. For example, following the increase of H_2S in the feed biogas, the system performance indicators pointed to the low nutrient and O_2 levels to sustain biological activity, and these conditions were corrected.

Conclusions: The biological scrubber performed very well and is a very cost-effective system. It has capacity to be an easily implementable technology with robust performance controls, allowing reliable H_2S removal from digester gas without daily use of chemicals.

Application of Findings to California: The biological scrubber has significant economic and environmental benefits and is a good candidate to be installed at many other locations in California. The testing of the unit at IEUA RP-1 documented that it could be installed efficiently at existing facilities meaning that it could be used in a variety of applications where H_2S removal from gas streams is needed with low operational cost.

4.3 Project 2.2 Recommendations

- Initiate a technology transfer program to communicate the effectiveness of biological scrubbers to potential users. Communicate that the scrubbers perform well from a technical, economic, and environmental standpoint. Explain that their deployment at wastewater treatment plants across the state would reduce chemical use, reduce solid waste disposal activities (required if other types of media are used), and lower the cost of using biogas.

- Complement the technology transfer program outlined above with additional testing on digester gas generated from biosolids and on systems larger than that used in the RP-1 test. That test was on biogas from a manure digester and was equivalent to a treatment plant with a flow of about 5 to 10 million gallons per day. Running such additional testing on digester gas from biosolids would provide long term results facilitating optimization of future full scale systems.

- Conduct future research to optimize a combined system of chillers and media-based systems to remove siloxane and hydrogen sulfide. Removing siloxane and hydrogen sulfide as part of the moisture removal system is an option because dual benefits result when using such moisture removal systems. Different media were also demonstrated to perform well for siloxane removal. Therefore, further testing of combined chiller/media systems, where the chiller is operating at less than 40°F and above -40°F, would be optimal. Additional research is merited to help define the parameters of such optimized systems.
- Systems that inject air into iron sponges prolong their life and are cost-effective. The major drawback to such systems is maintaining pH at proper levels with chemicals. It is important to find chemicals that do not clog the feed nozzles. Chemicals other than lime should be tested to determine their effectiveness in maintaining the proper pH while avoiding nozzle clogging.
- Additional research using ultrasound as a tool to increase biogas production and solids destruction should be limited to "stressed" systems. Such systems, where there is limited holding time available because of digester capacity constraints, are candidates for ultrasound, but systems operating under normal operating conditions are not good candidates for ultrasound.

Focus future ultrasound research on systems with sonic horns 6 kW or smaller. The larger horns are not as reliable or as effective as the smaller horns and should not be used in future research on wastewater treatment plant applications until the technology advances and becomes more reliable.

GLOSSARY

BIPV	Building Integrated Photovoltaic
cf/d	cubic foot per day
cf/lb	cubic foot per pound
DAFT	dissolved air flotation thickeners
Energy Commission	California Energy Commission
GHG	greenhouse gas
H_2S	hydrogen sulfide
IEUA	Inland Empire Utilities Agency
kW	kilowatt
MW	megawatt
MWh	megawatt per hour
PIER	Public Interest Energy Research
ppm	part per million
PV	photovoltaic
RD&D	Research, Development, and Demonstration
REDI	Renewable Energy Development Institute
SCAQMD	South Coast Air Quality Management District
SJVAPCD	San Joaquin Valley Air Pollution Control District
TS	total solid
TWAS	thickened waste activated sludge
VS	volatile solid
VSR	volatile solid reduction
WWTP	wastewater treatment plan
ZECO	Zaininger Engineering, Inc.

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